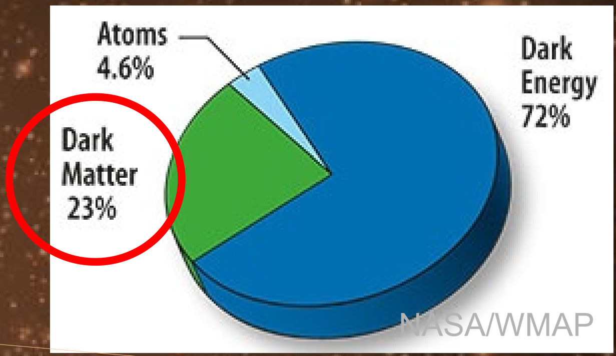
z=0.0

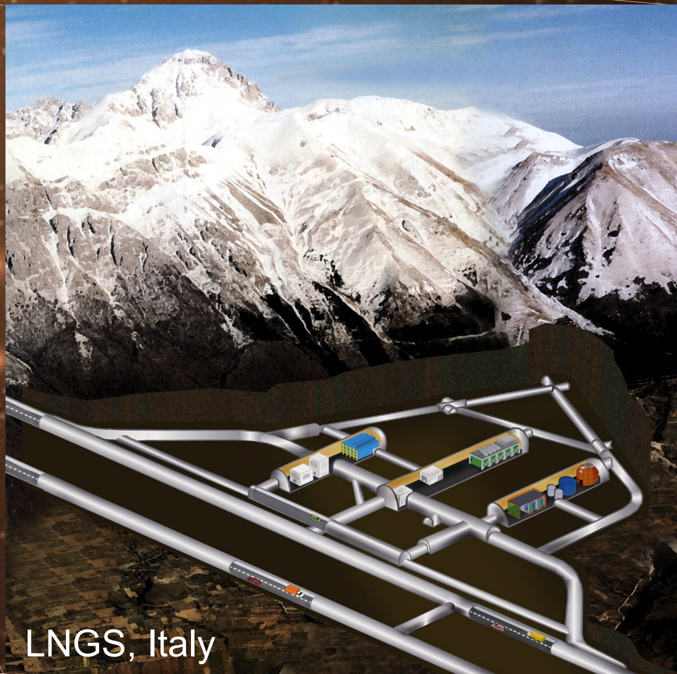
Via Lactea 2 (2008)
http://www.ucolick.org/~diemand/vl

Direct Searches for WIMP Dark Matter

KET Strategie-Workshop 2010
Dortmund

26. Nov. 2010





Uwe Oberlack

JOHANNES GUTENBERG UNIVERSITÄT MAINZ

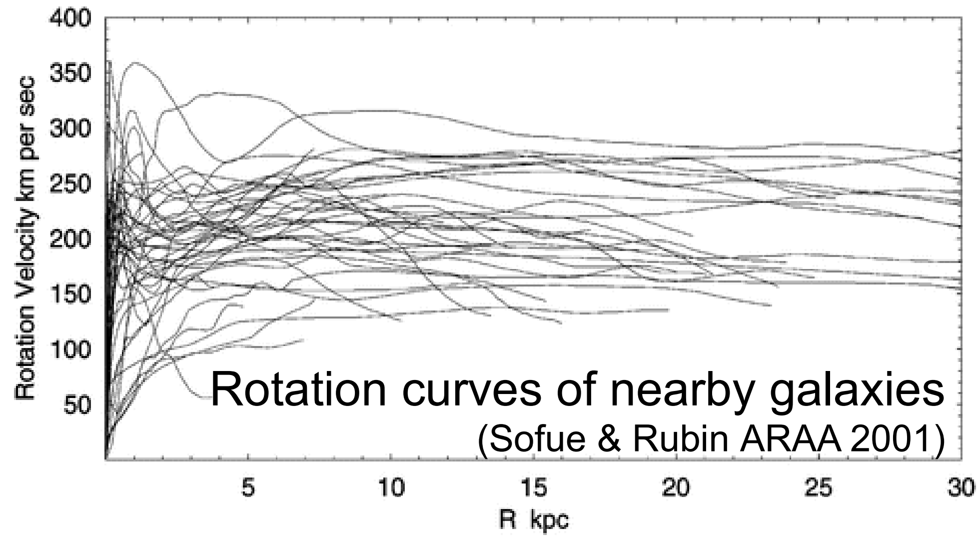
80 kpc

Evidence for Dark Matter
at Different Astrophysics Scales

Spiral Galaxies Scale: ~10^{21} m

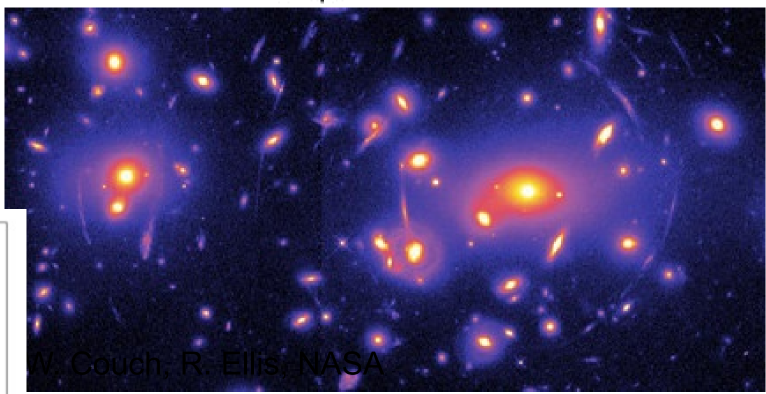
Rotation curves remain flat far beyond the edge of the visible disk.

$$\left.\begin{array}{lcl} v(R) & = & \sqrt{GM(R)/R} \\ v(R) & \approx & const \end{array}\right\} \Rightarrow \left\{\begin{array}{lcl} M(R) & \propto & R \\ \rho(R) & \propto & R^{-2} \end{array}\right.$$



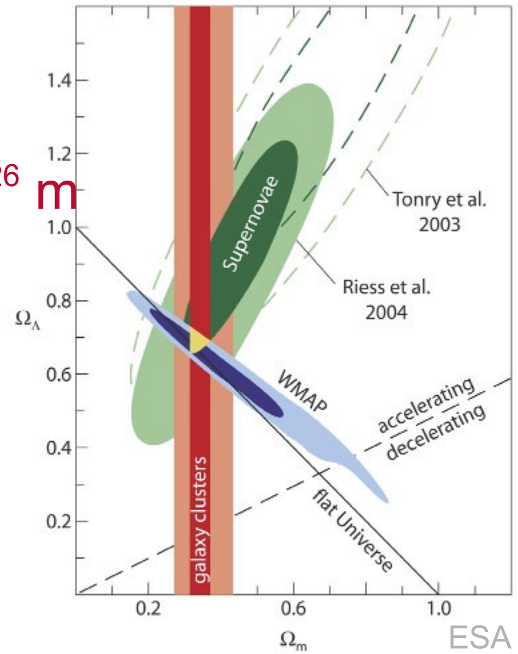
Galaxy Clusters Scale: ~10^{22} m

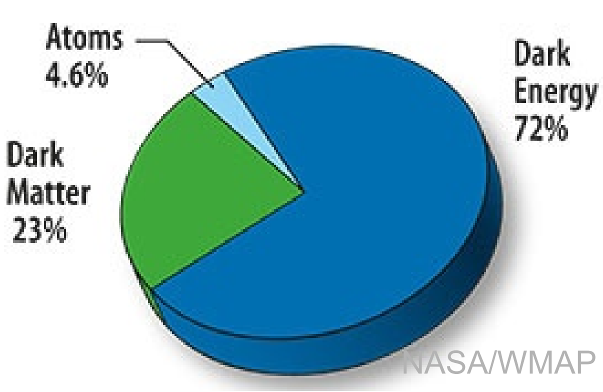
- Orbital velocities of galaxies (Zwicky's discovery in 1933)
- X-ray gas
- Gravitational lensing



The Dark Universe - Scale: ~10^{26} m

- CMB: Ω_{tot}=1.0
- CMB, BBN: Ω_b=0.045
- Galaxy clusters: Ω_m=0.27
- Supernovae Ia: Ω_m, Ω_Λ
- Structure formation: cold DM

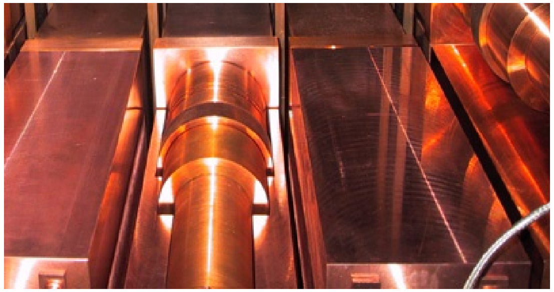


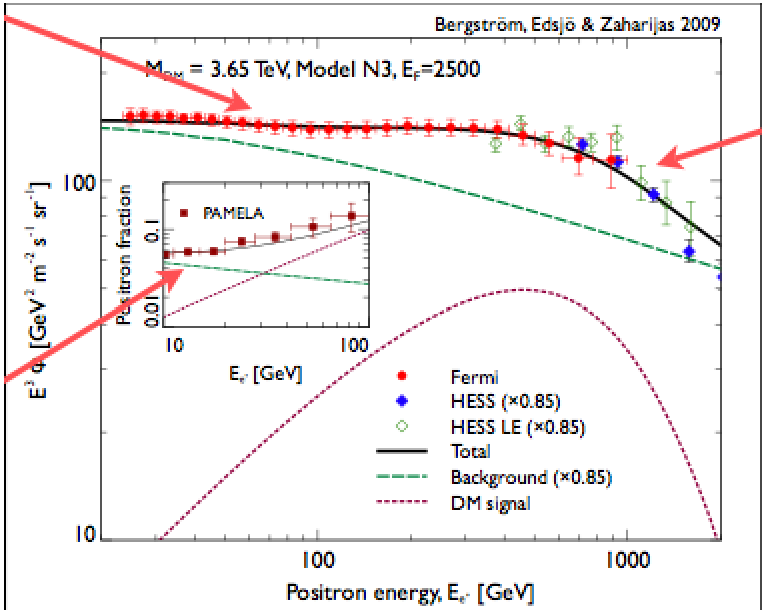


Physics beyond SM!

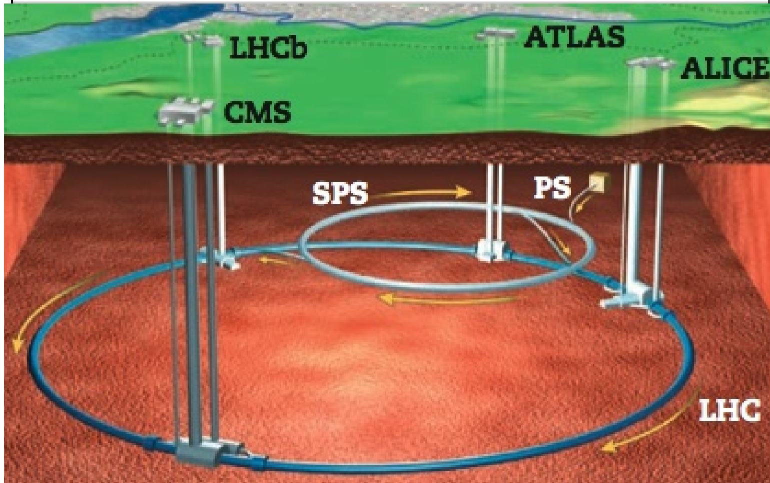
Dark Matter Detection Methods

- Astrophysics / Cosmology:
  Measurement of Gravitational Effects.
  - Rotation curves of spiral galaxies
  - Orbital velocities of galaxies in clusters (Zwicky 1933)
  - Colliding clusters (Bullet cluster)
  - Large scale structure, lensing
- **Direct Detection:**
  - **WIMP scattering**
  - Axion searches

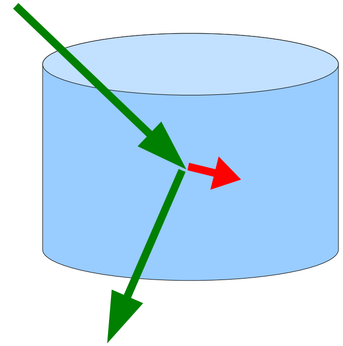




- Indirect Detection: from annihilation or decay
  - Cosmic rays
    PAMELA positron excess?
    Fermi, ATIC, HESS electron spectrum? Anti-deuterons?
  - Neutrinos
  - Gamma-rays
- Accelerator-based Creation and Measurement:
  - Missing energy / momentum
  - Search for related particles (SUSY, extra dimensions) even if not the DM particle itself



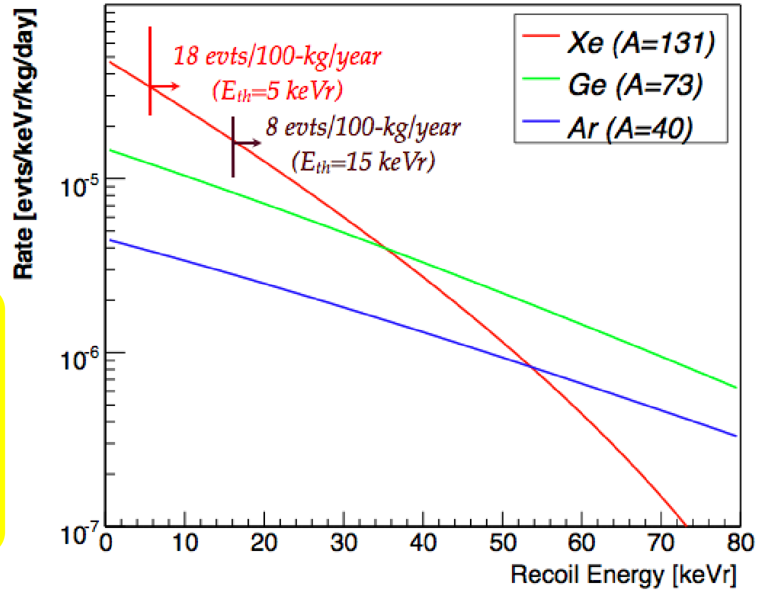
WIMP Dark Matter Direct Detection



- Dark Matter is non-bayonic, (rather) cold, ...
  - if a thermal relic from the Big Bang ...
  - Weakly Interacting Massive Particles: WIMPs
- Scattering of WIMPs χ off of nuclei A.
  - elastic or inelastic?
  - spin-independent ($\sim A^2$) or spin-dependent?
- Energy spectrum:

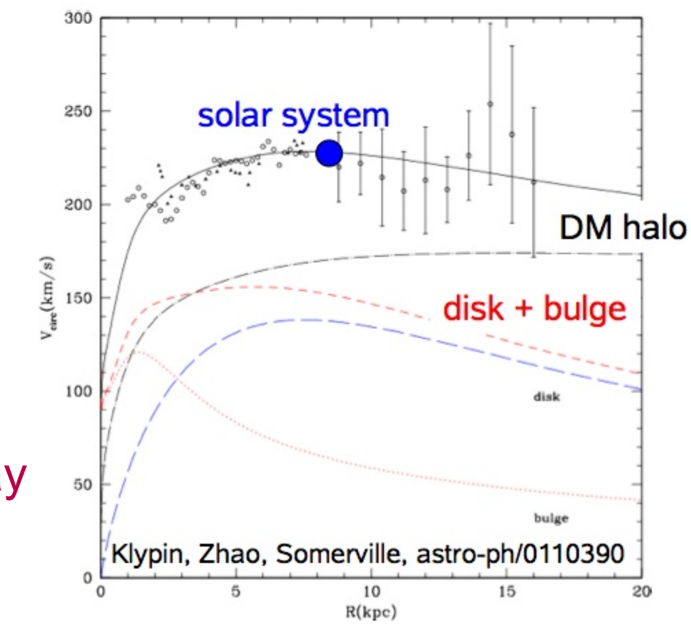
$$\frac{dR}{dE} = \frac{\rho_\chi \sigma_s}{2 m_\chi \mu^2} |F(E)^2| \int_{v_{min}}^{v_{esc}} \frac{f(\mathbf{v},t)}{v} d^3 v$$

$$f(\mathbf{v},t) \propto \exp\left(\frac{-(\mathbf{v}+\mathbf{v}_E(t))^2}{2\sigma_v^2}\right)$$



- $m_\chi \sim 10 - 10^4$ GeV/c^2, $\mu = (m_\chi m_n)/(m_\chi + m_n)$
- $v_\chi \sim 230$ km/s
- "Standard" spherical halo:
  Featureless recoil spectrum <E> ~ O(10 keV)
- ρ_χ/m_χ: local number density of WIMPs
- $\rho_\chi \sim 0.3$ GeV/c^2/cm^3, $\rho_\chi/m_\chi \lesssim 10$ / L
- σ_s cross section per nucleus.

Rate < 10^{-2} events / kg / day



DM Detector Overview
Detection Principles

Bubble Formation
COUPP, PICASSO

Tracking
Drift, DM-TPC, NIT

Ionization
CoGeNT

CDMS-II, Super-CDMS
EDELWEISS-II

LAr: WARP, ArDM
LXe: **XENON**, LUX, Zeplin

Phonons

CRESST-II,
ROSEBUD,
EURECA

Scintillation
DAMA/LIBRA
KIMS, XMASS,
DEAP/CLEAN

Direct DM Searches - Worldwide

! Sensitivities also depend on
- Background
- A^2
- Energy threshold

CRYOGENIC

Phonon+Scintillation

CRESST
EURECA
Germany, UK, Italy

Phonon+Ionization

EDELWEISS
EURECA
France, Germany, UK, Russia

Super CDMS
GeoDM
US, Canada, Switzerland

Run: 3-4 kg *tot.*
Prepare: ~15 kg 2011
Plan: ~100 kg 2015
~1 t >2015

LIQUID NOBLE GASES

Dual Phase (Scintillation + Ionization)

XENON

XENON
US, Switzerland, Italy, Portugal, Germany, France, Netherlands, China, Israel
Run: 40 kg *fid.*
Plan: 1.0 t *fid.* 2013

LUX
10 US institutions, Moscow
Prep.: ~150 kg *fid. 2011*

ARGON

WARP
Italy, US
Prepare: ~140 kg *fid.*

ArDM
Switzerland, Spain, UK, Poland
Prepare: ~100 kg *fid.*

Single Phase (Scintillation)

XMASS
10 institutions from Japan
Prep.: ~100 kg *fid.* 2010

DEAP / CLEAN
Canada, US
Prepare:
MiniClean ~150 kg *fid.*
DEAP-3600 ~3.6 t *tot.*

LXe: Run 40 kg *fid.*
Prep. 150 kg *fid.* 2011
Plan: 1 t *fid.* 2013

LAr: all prepare / plan
~100-300 kg *fid.* 2011-13

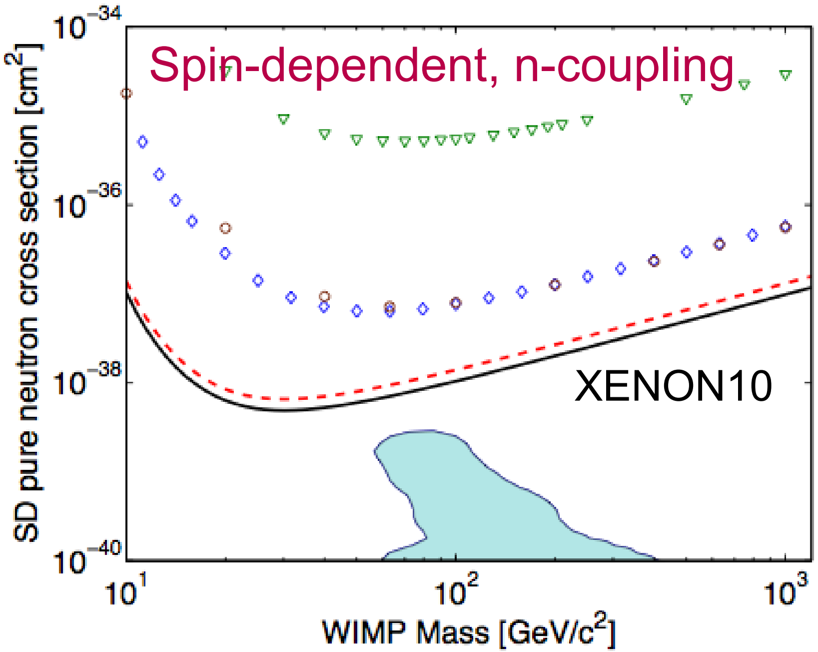
Superheated Liquids

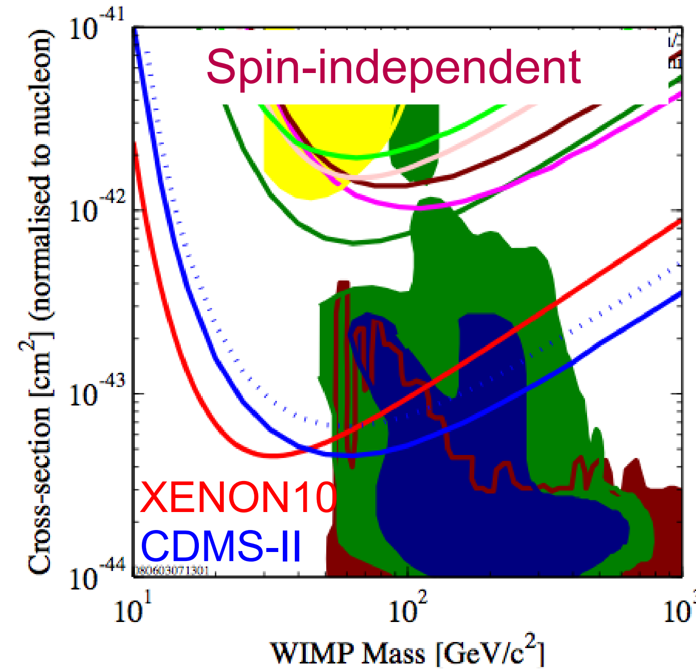
COUPP
USA
Run: 4 kg
Plan: 60 kg

PICASSO
Canada, USA, Czech Rep., India

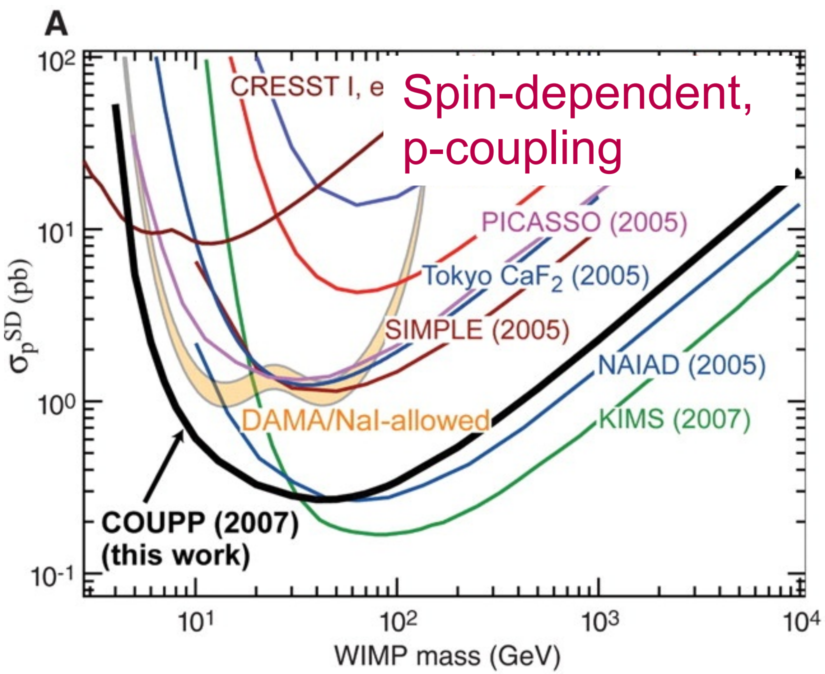
Prepare / run few kg.
Background-dominated so far.
Good SD limits.
Outlook: With acoustic discrimination, expect substantial background improvement.
COUPP can potentially also have good SI sensitivity on longer term.

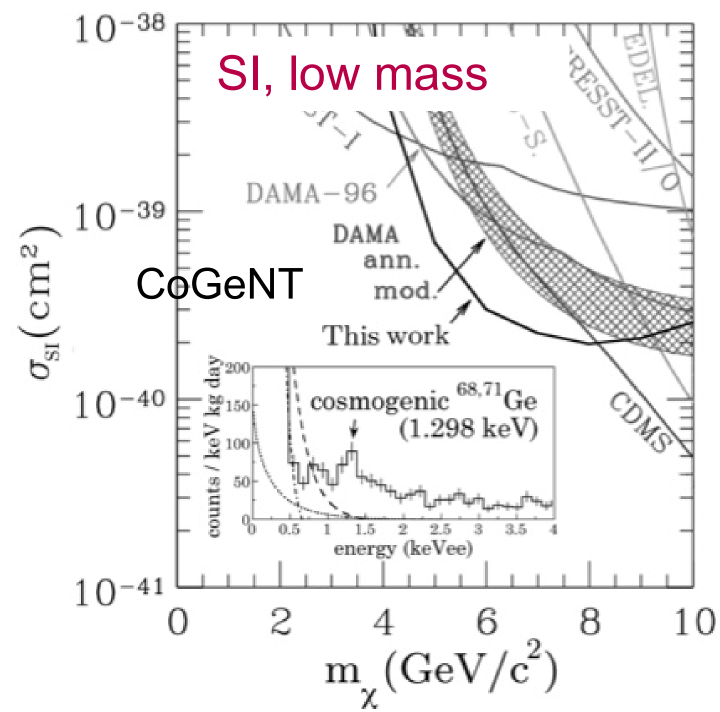
Status in WIMP DM Sensitivities (2009)



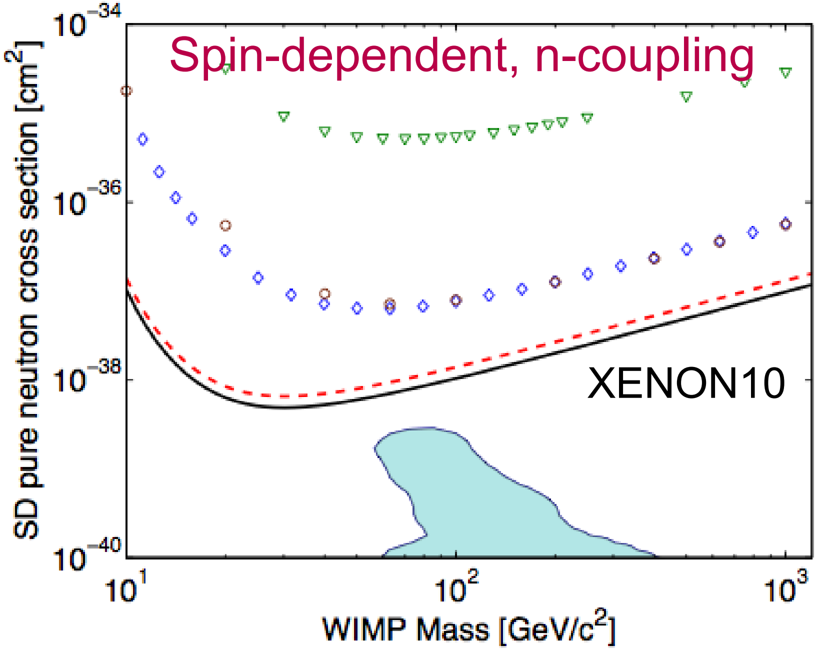


- J. Angle et al., 2008 PRL 101 091301 (XENON10 SD)
- J. Angle et al., 2008 PRL 100 (2) 021303 (XENON10 SI)
- Z. Ahmed et al., arxiv:0802.353v1 (CDMS-II SI)
- C.E. Aalseth et al. arxiv:0807.0879v1 (CoGeNT SI)
- E. Behnke et al., 2008 Science 319, 933 (COUPP SD)
- Recent additions (not plotted): Zeplin-III SI, SD arxiv:08/09 limits ~ Xe10





Status in WIMP DM Sensitivities (2010)



XENON10 SD, 2008
PRL 101 091301

XENON10 SI, 2008
PRL 100 (2) 021303

XENON100 SI, 2010
PRL 105, 131302

CDMS-II SI, 2010
Science 327, 1619

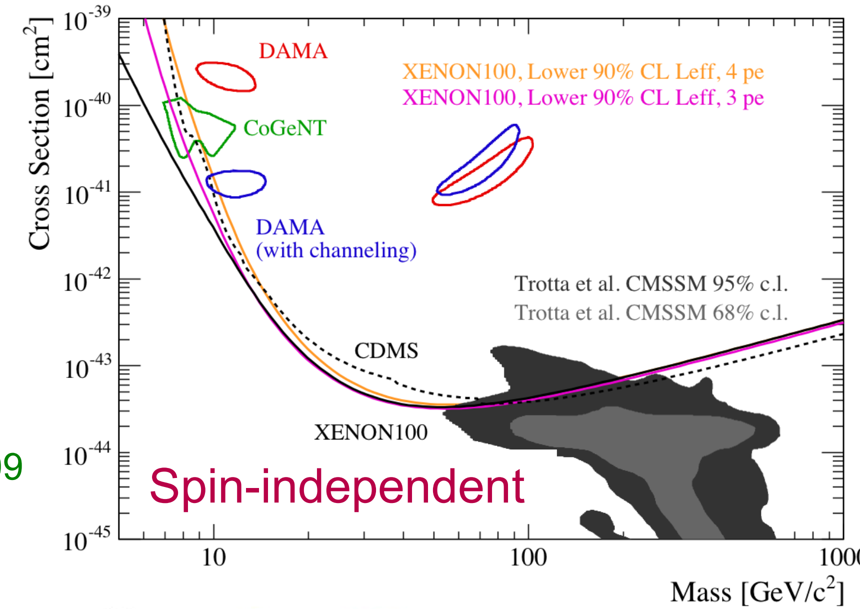
EDELWEISS-II SI, 2009
Phys Lett B 681, 305

CoGeNT SI, 2010
arxiv:1002.4703

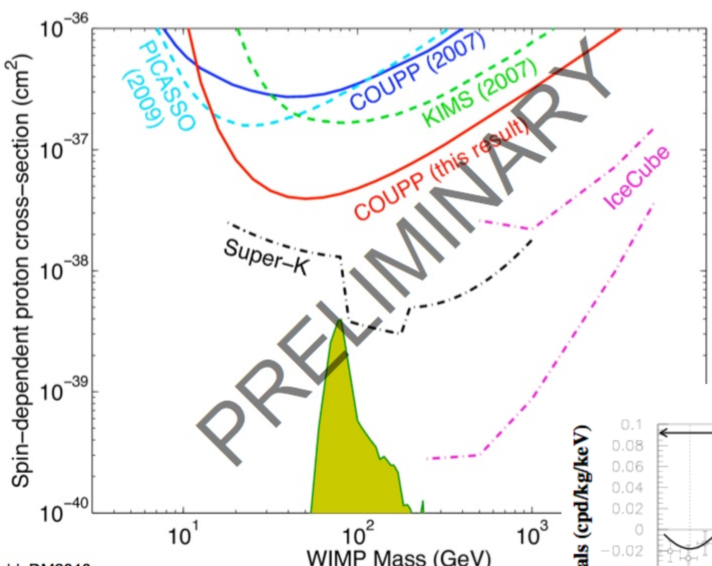
COUPP SD:
2008: Science 319, 933
2010: prelim: DM2010 conf.

PICASSO SD, 2009
Phys.Lett. B 682, 185

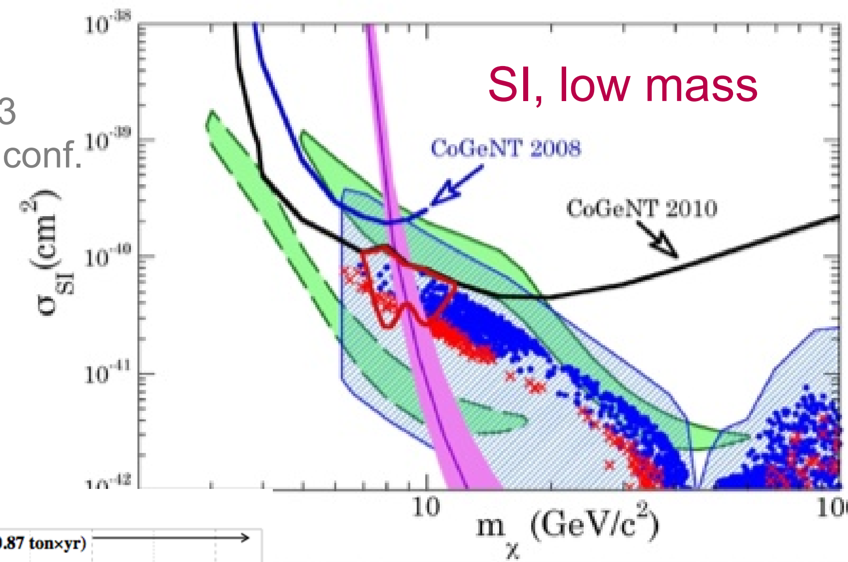
DAMA/LIBRA, 2010
arxiv:1002.1028



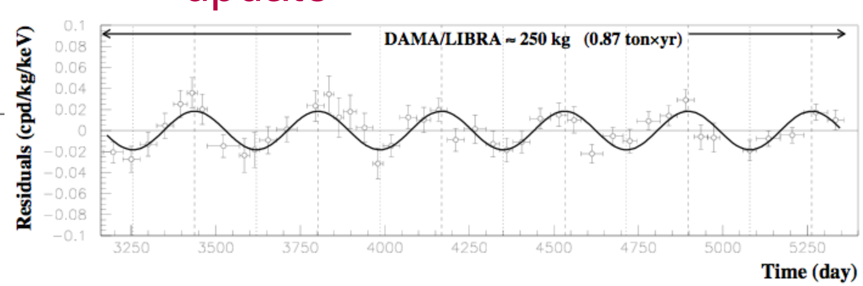
Spin-dependent, p-coupling



C.E. Dahl, DM2010
February 26, 2010



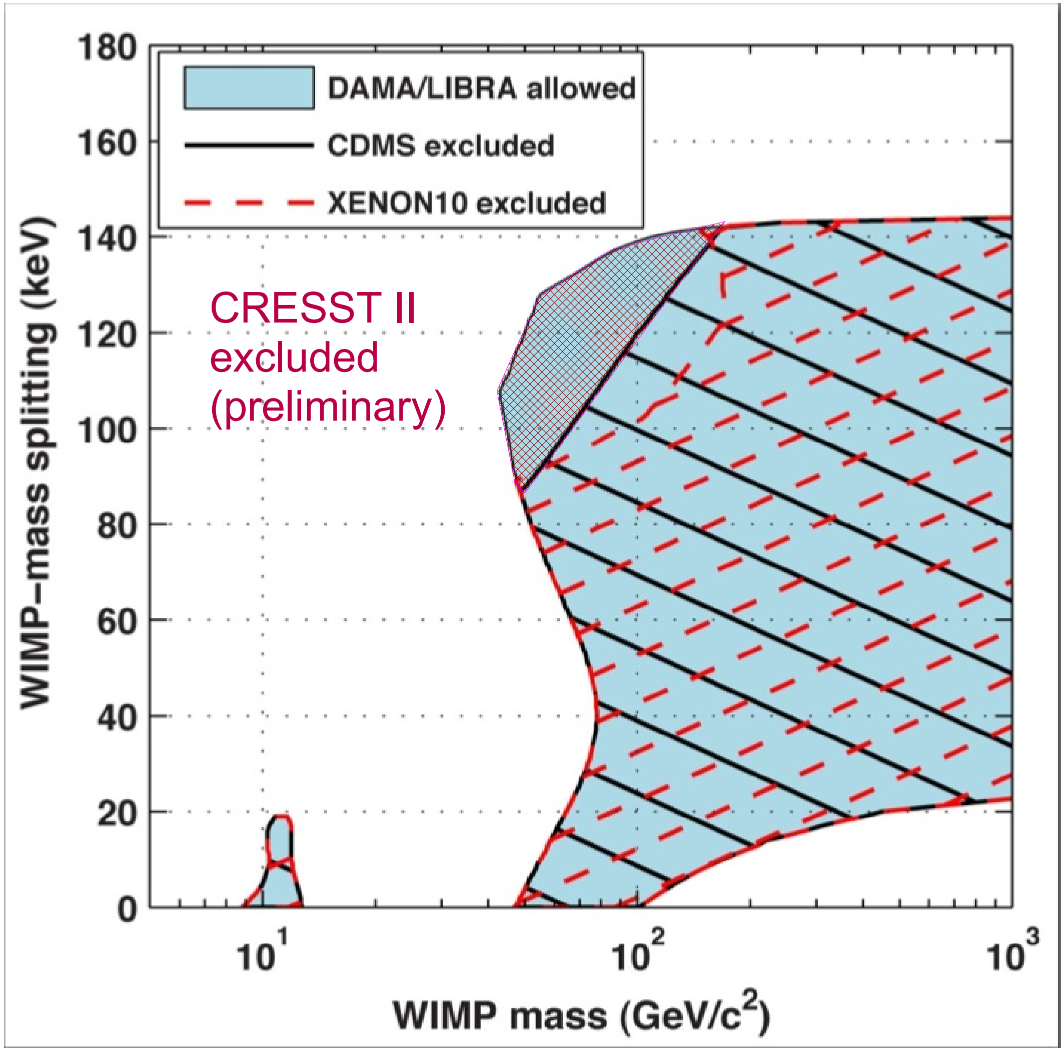
Annual modulation update



Uwe Oberlack

Inelastic Dark Matter Limits

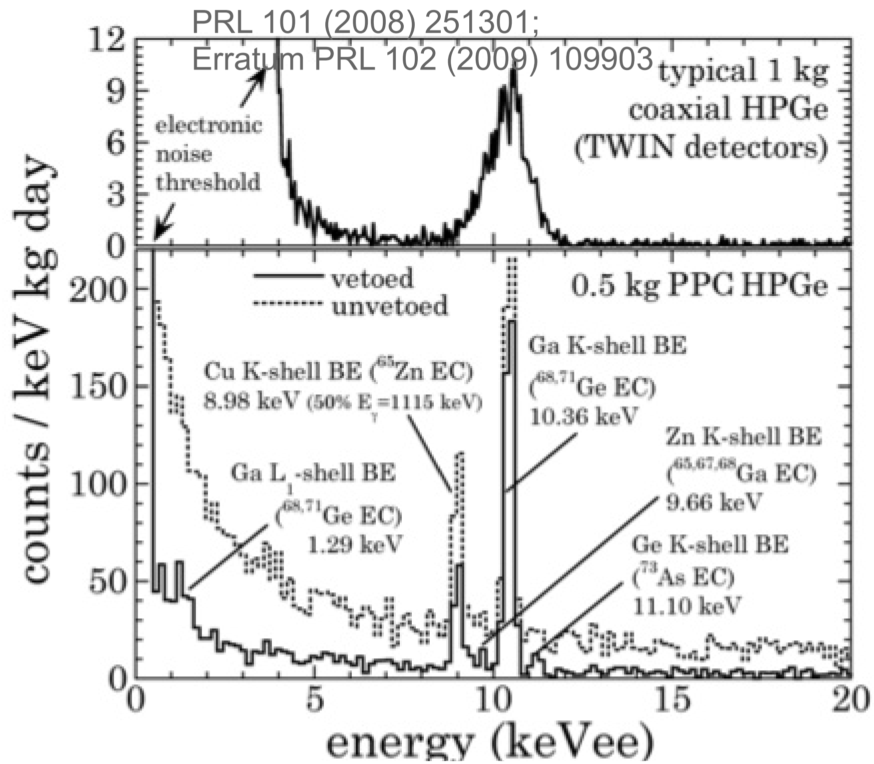
- Assume DM can scatter only in a low-lying excited state, i.e., elastic scattering is suppressed.
- This makes DAMA/LIBRA annual modulation still compatible with XENON10 & CDMS in a parameter space with energy splitting ~90 – 140 keV at WIMP masses 50 – 140 GeV/c^2.
- XENON100 will cover the entire allowed parameter space at very low background.
- CRESST-II excludes the remaining parameter space (*preliminary*).
- If confirmed, the standard inelastic DM model can be put to rest to explain the conflict between DAMA/LIBRA and other experiments.

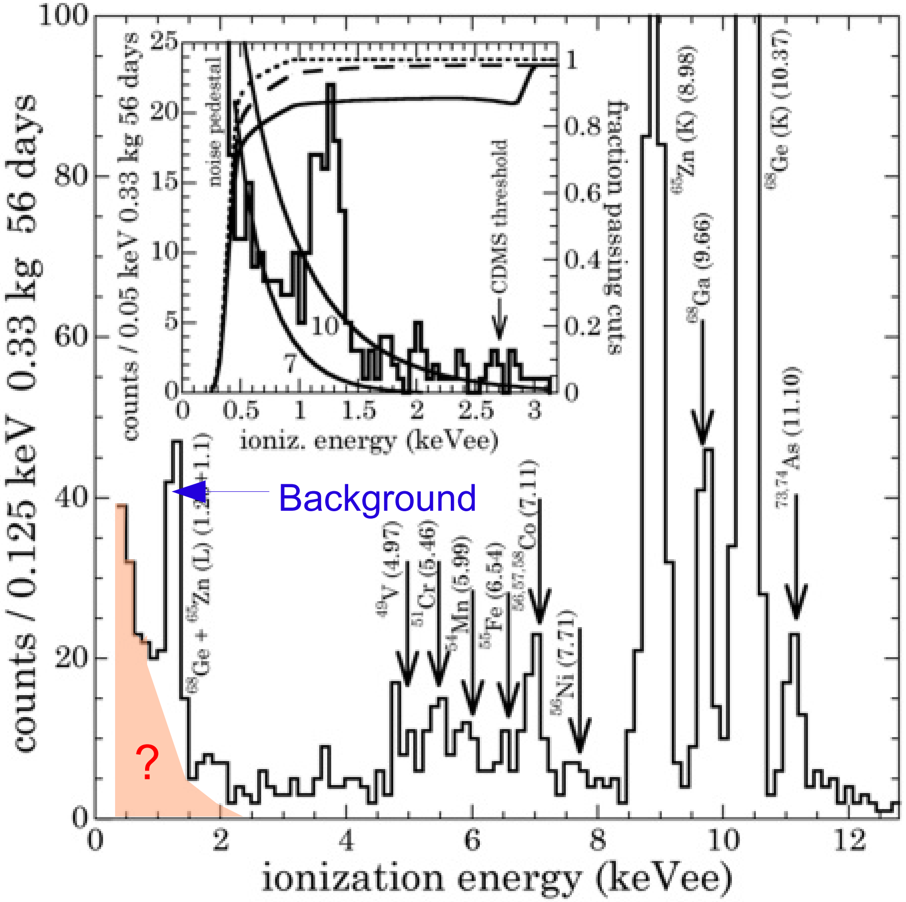


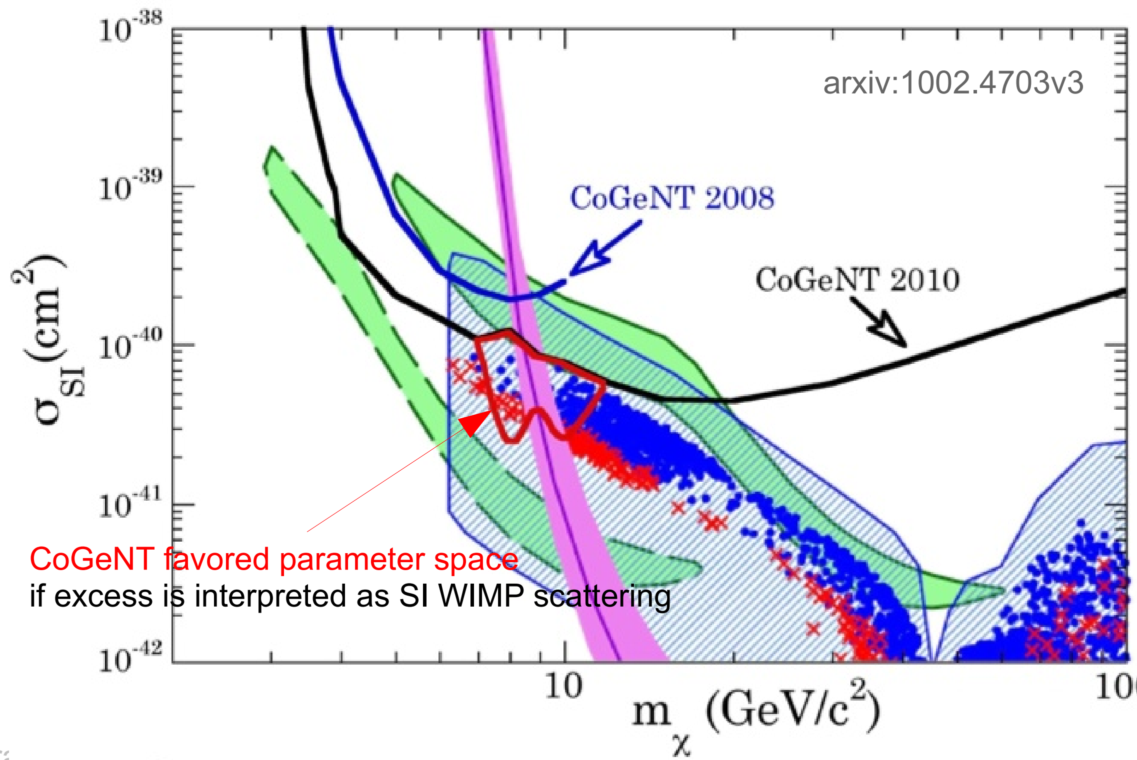
CoGeNT: What are these excess counts?

Did anyone mention Low Mass WIMPs?

- P-type point contact (PPC) Germanium detectors:
  - 440 g mass per detector (CDMS: 250 g)
  - low electronic noise, hence low threshold (0.4 keVee)
- Located in Soudan mine (2100 mwe)





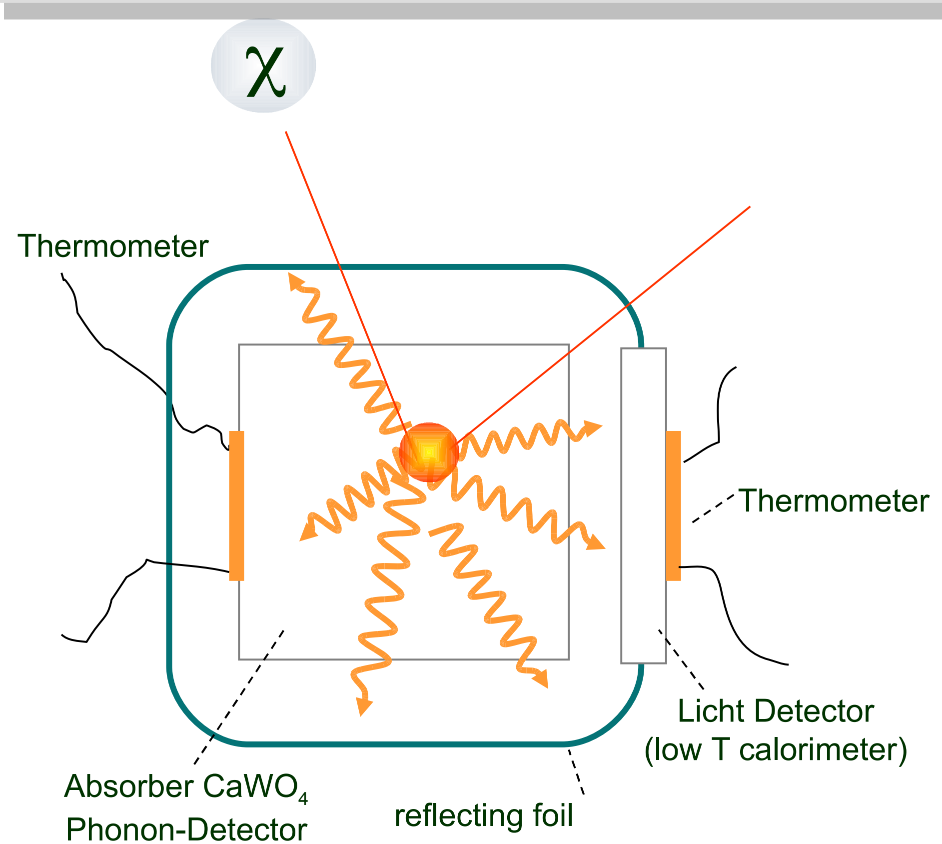


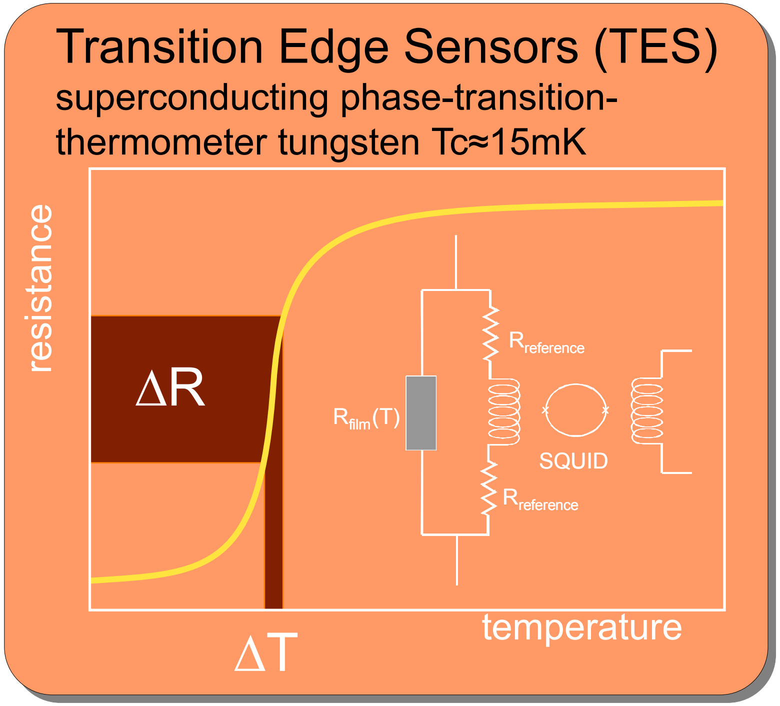
CRESST II: Phonons + Scintillation

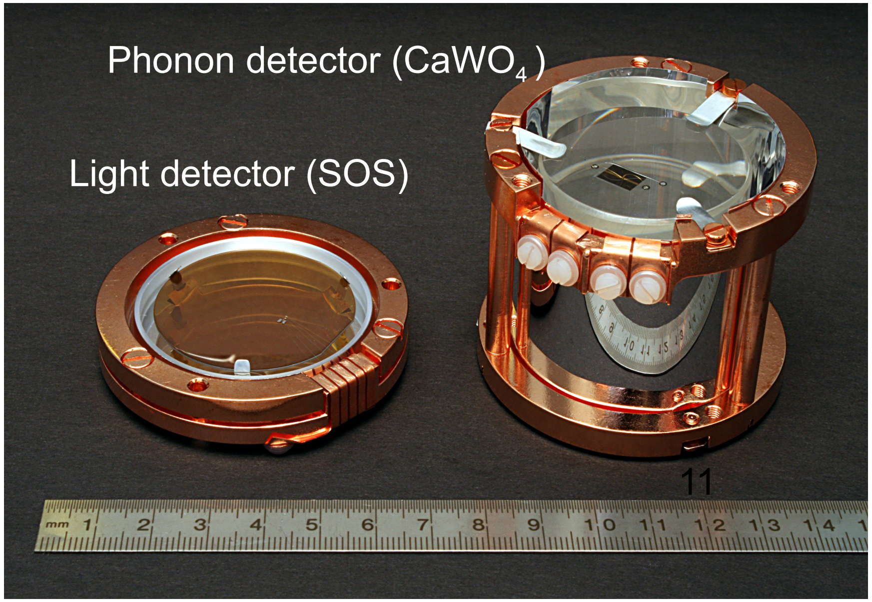
CRESST
Cryogenic Rare Event Search with
Superconducting Thermometers

light + phonons (scintillating crystals)

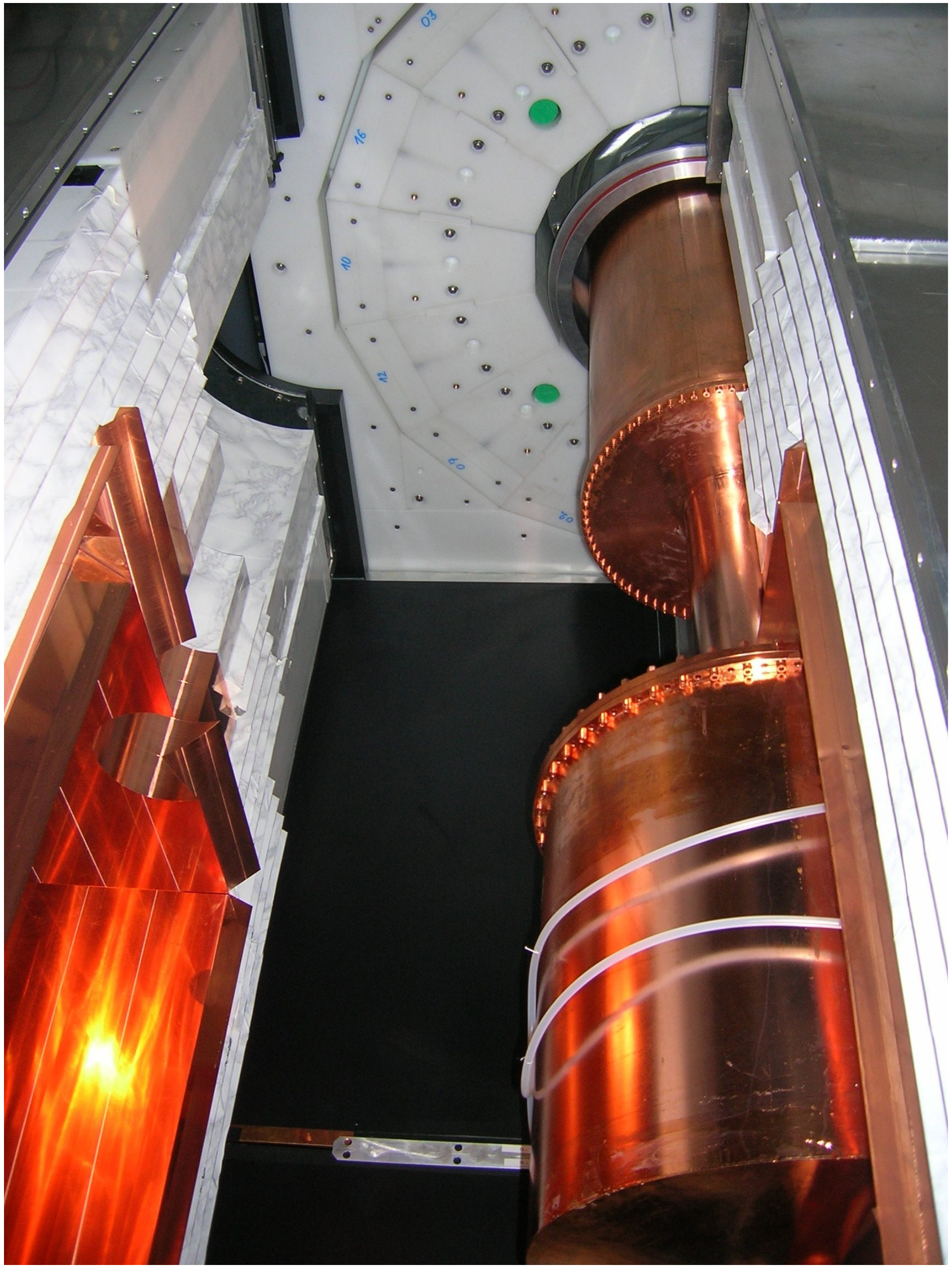
Max-Planck-Institut München, TU München
Universität Tübingen, Oxford University, Gran Sasso

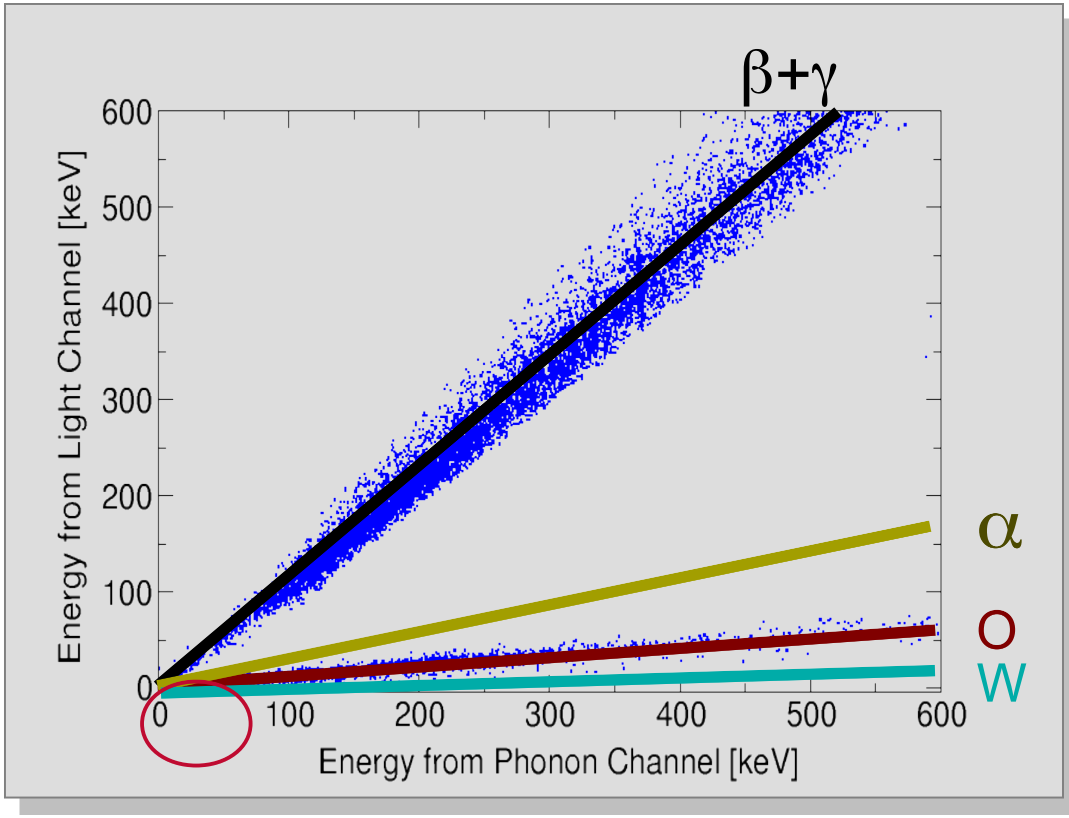






CRESST II Background Suppression & Discrimination

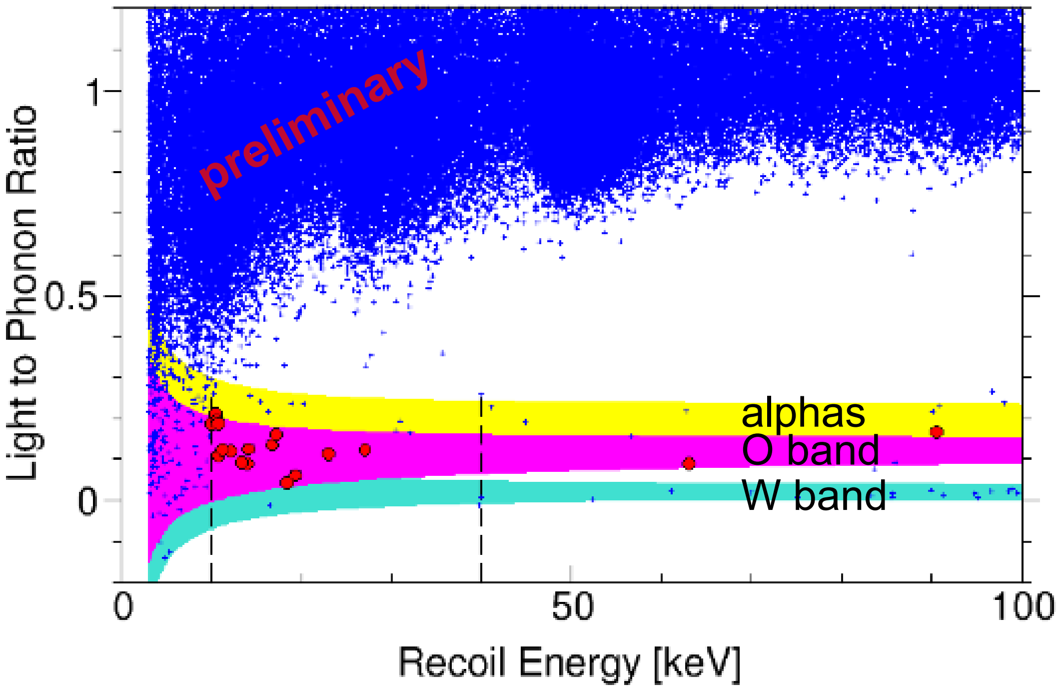


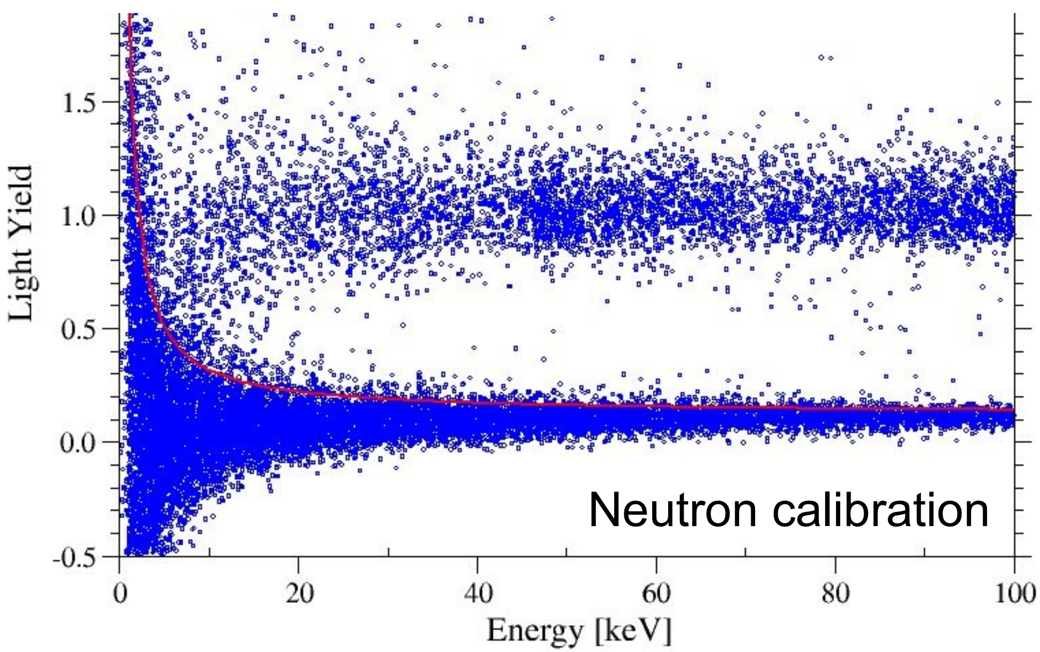


- Polyethylene / Lb / Cu passive shield
- Plastic muon veto
- Light yield / Phonon Energy = background discriminator
- CRESST unique feature: multi-target possible

CRESST: What are these excess counts?

Did anyone mention Low Mass WIMPs?



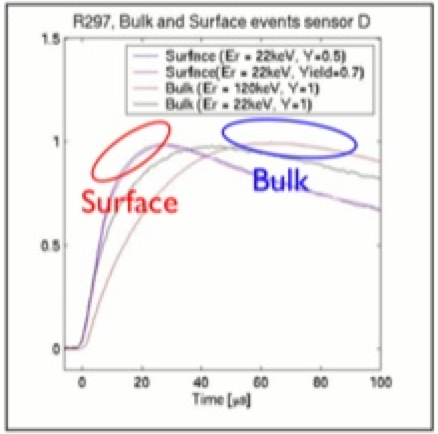


- Data from 9 CaWO4 detectors (333kgd) (analysis still in progress)
- Region of interest W-band 10–40 keV
- Elastic DM limit: upper 10^{-8} pb
- Recoils on oxygen (red dots) identified in all detectors
- Explainable with neutrons ?
- Leakage of α and/or γ events ?
- Estimates of conventional background can only explain ~1/3 of the observed events.
- Hint for low-mass (<10 GeV) WIMPs?
- *see DAMA/LIBRA and CoGeNT ...*

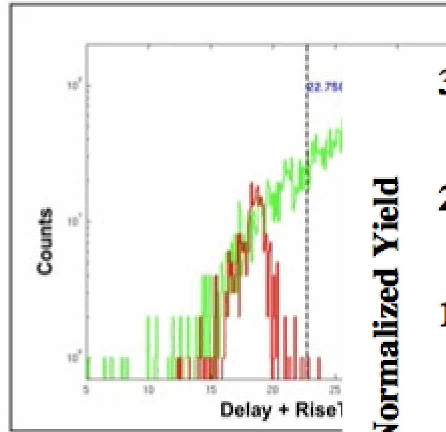
ace
vents:

athermal photons
ensitive to surface

fficiency 10^{-6}

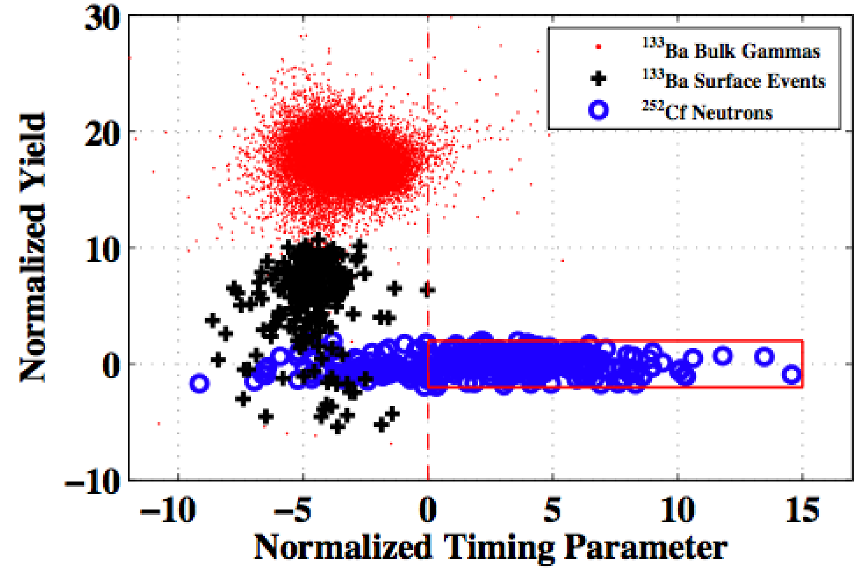


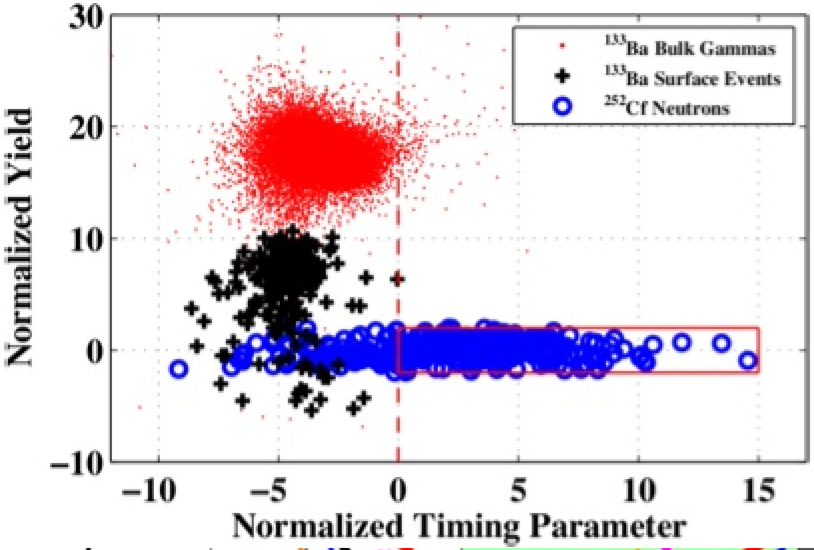
Phonons near surface travel faster, resulting in shorter risetimes of phonon pulse.



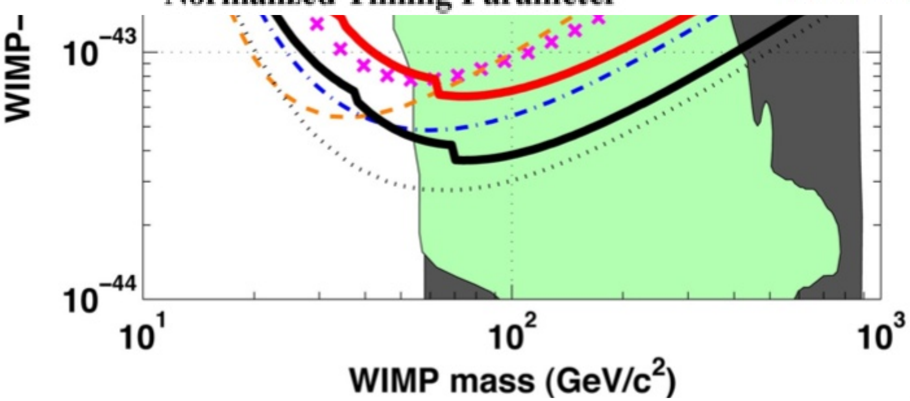
Selection criteria
~0.5 background

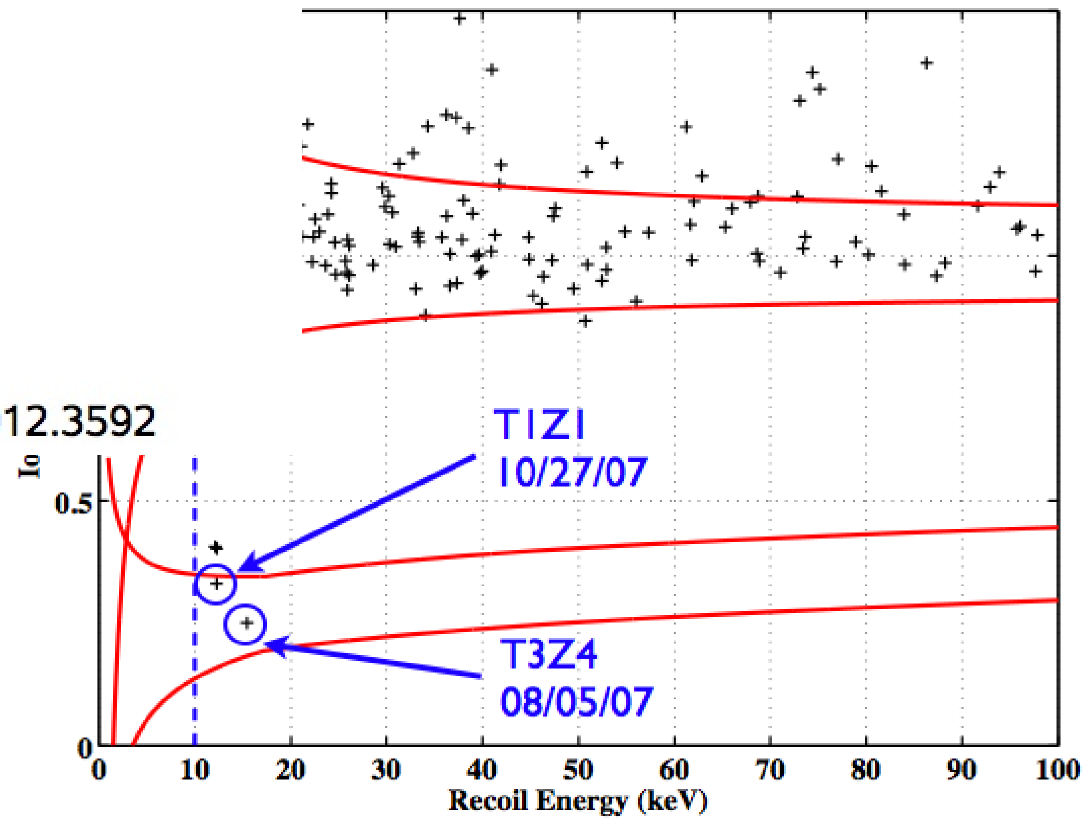
J. Cooley, SLAC,



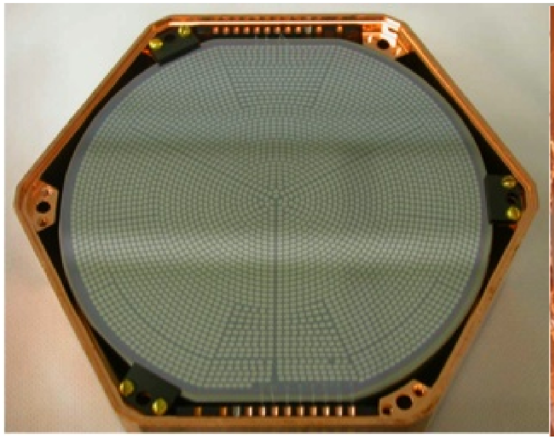


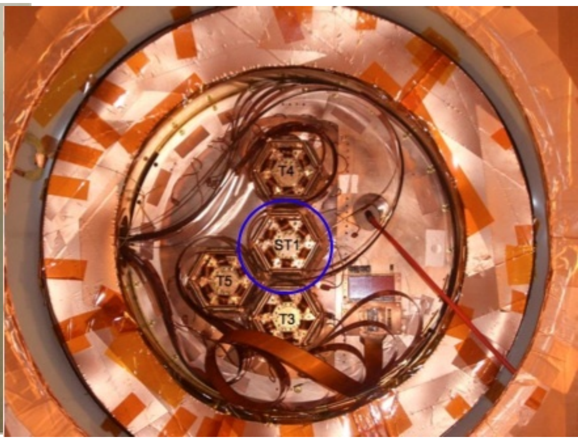
arXiv:0912.3592



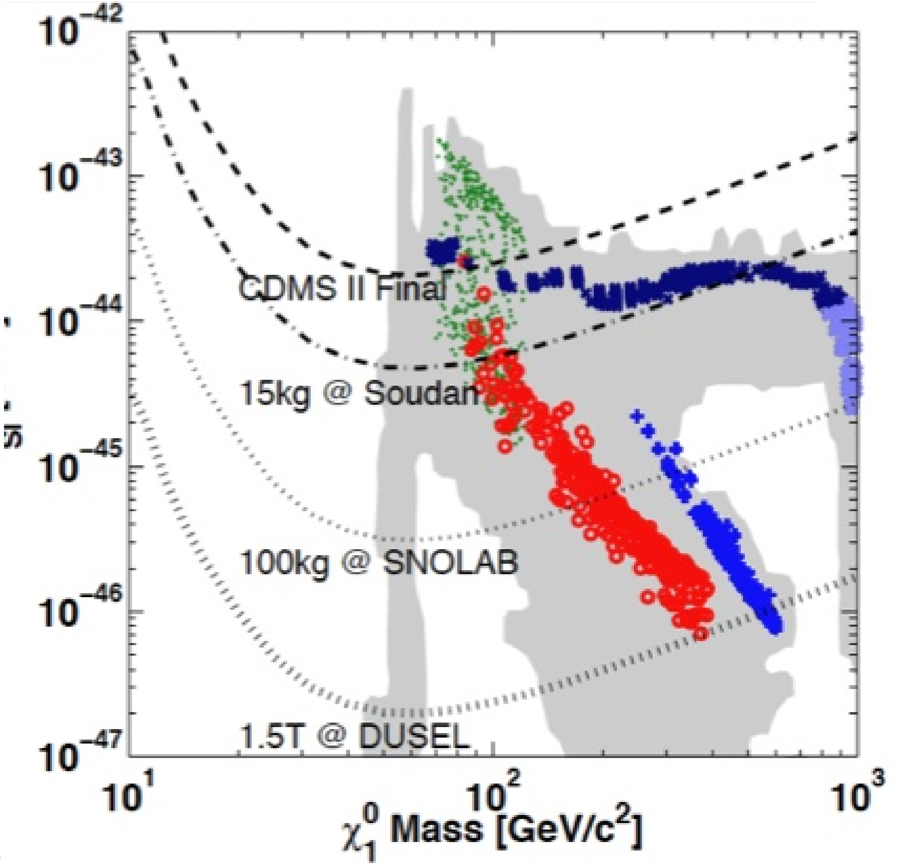


New Technologies for Large-Scale Cryogenic Germanium: Super-CDMS, Edelweiss / EURECA





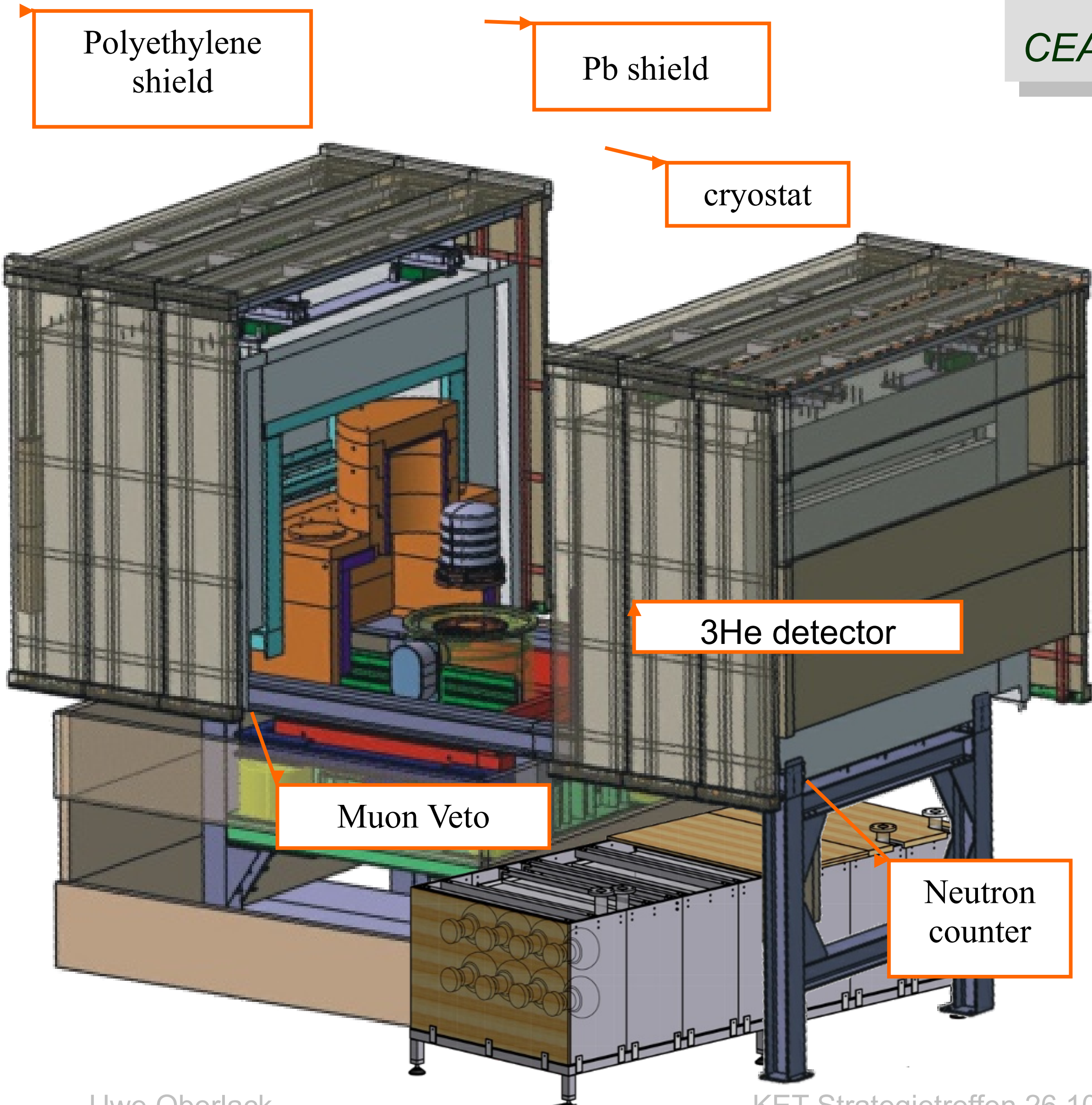
- Use semi-conductor industry production style to improve reproducibility and yield, reduce cost.
- Increase size of detectors.
  (250 g -> 607 g in Super-CDMS)
  Even 5 kg detectors possible?
- Initially Super-CDMS will remain in Soudan mine (~15 kg).
  Later: ~100 kg scale at deeper site (SnoLab).
- GeoDM ~1 t at DUSEL deep site ~2017
- EDELWEISS: success with surface background suppression using interleaved electrodes. Much superior over timing cut!
  Similar effort ongoing at CDMS (iZip).



Edelweiss II: Phonons + Charge
(Cryogenic Germanium)

EDELWEISS
Experience pour DEtecter Les Wimps En SIte Souterrain

CEA, CNRS, Oxford, Dubna, Sheffield, Karlsruhe



- Goal: $\sigma(\chi\text{-}n) = 5 \cdot 10^{-9}$ pb
- Cryogenic installation (18 mK) :
- Hosts up to 40 kg of detectors

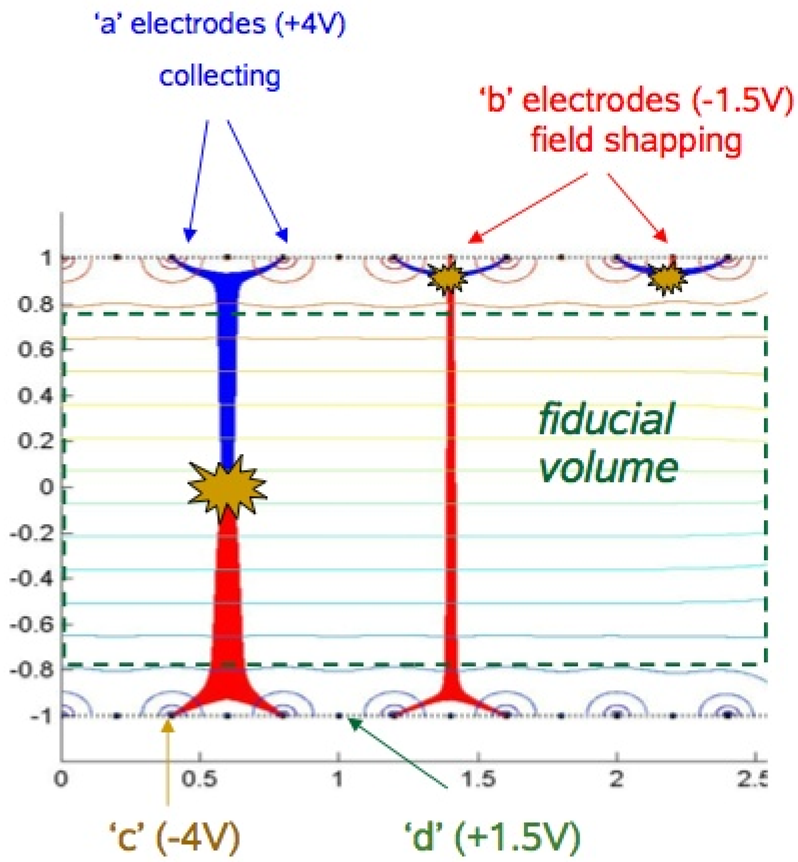
Shieldings:

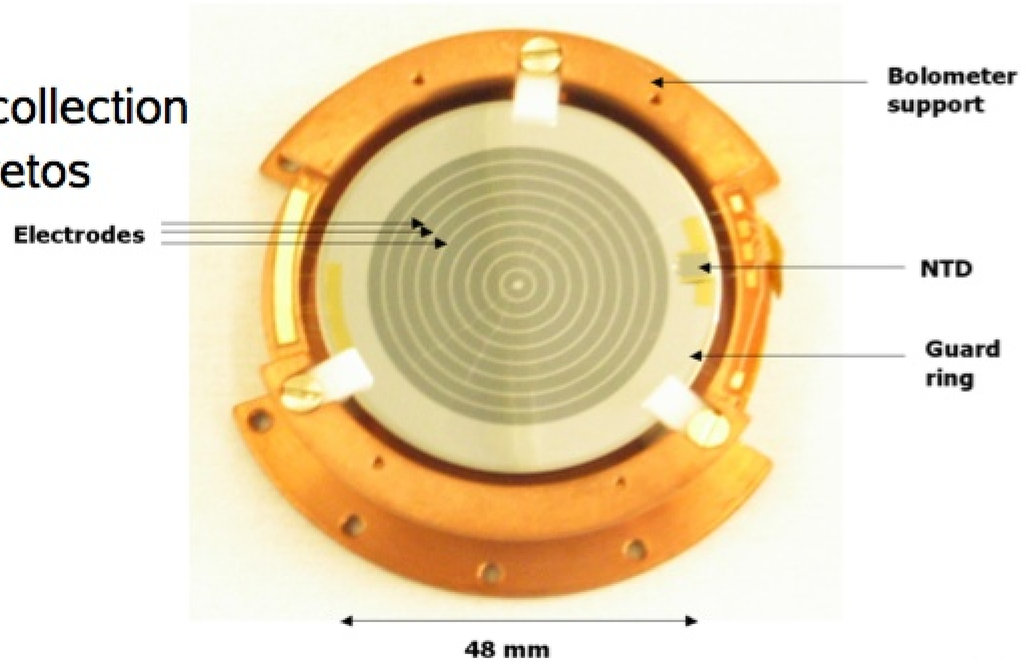
- Clean room + deradonized air
- Active muon veto (>98% coverage)
- PE shield 50 cm
- Lead shield 20 cm

$\Rightarrow$ γ background reduced by ~3 wrt EDW-1

Edelweiss – Interleaved Electrodes

Near surfaces:
Transversal E field to suppress charge collection to other side, use ‘b’ and ‘d’ signals as vetos without changing bulk field



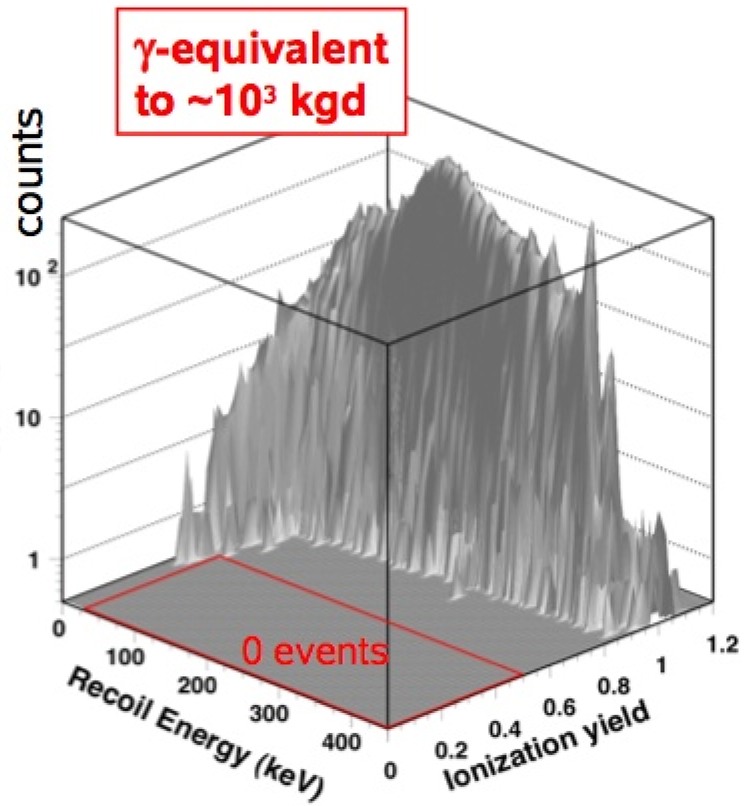


First detector built 2007
1x200g + 3x400g tested in 2008
10x400g running since beginning 2009

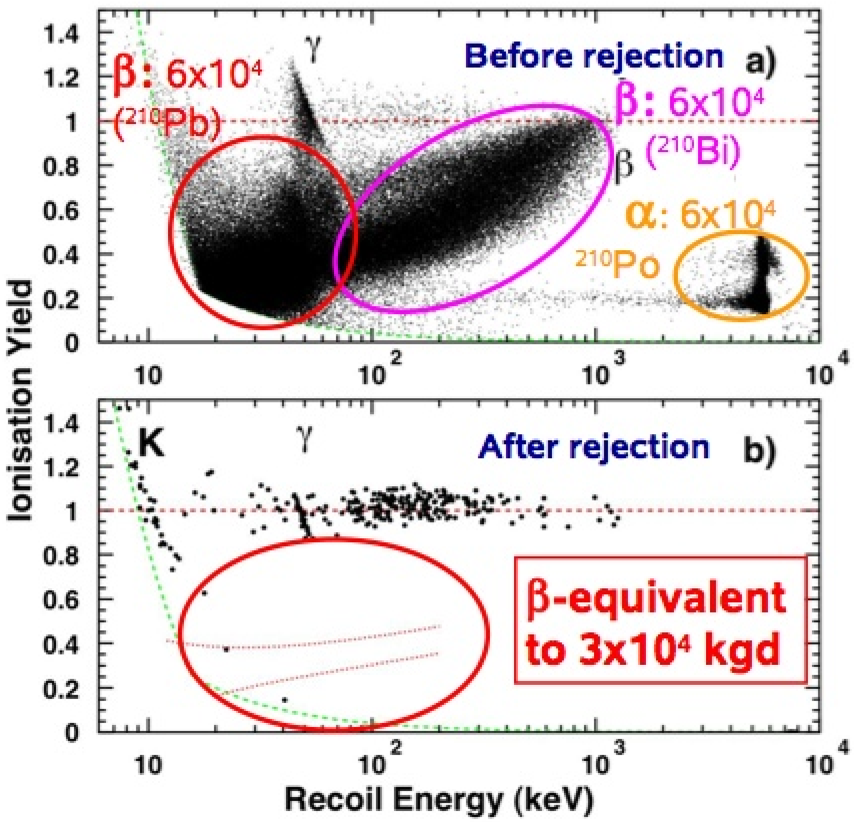
E. Armengaud, Colliquium APC, Feb 2010

Performance of Interleaved Electrode Detectors

- **Gamma rejection**
  ~1 month ^{133}**Ba** calibration (~10^5 γ´s)



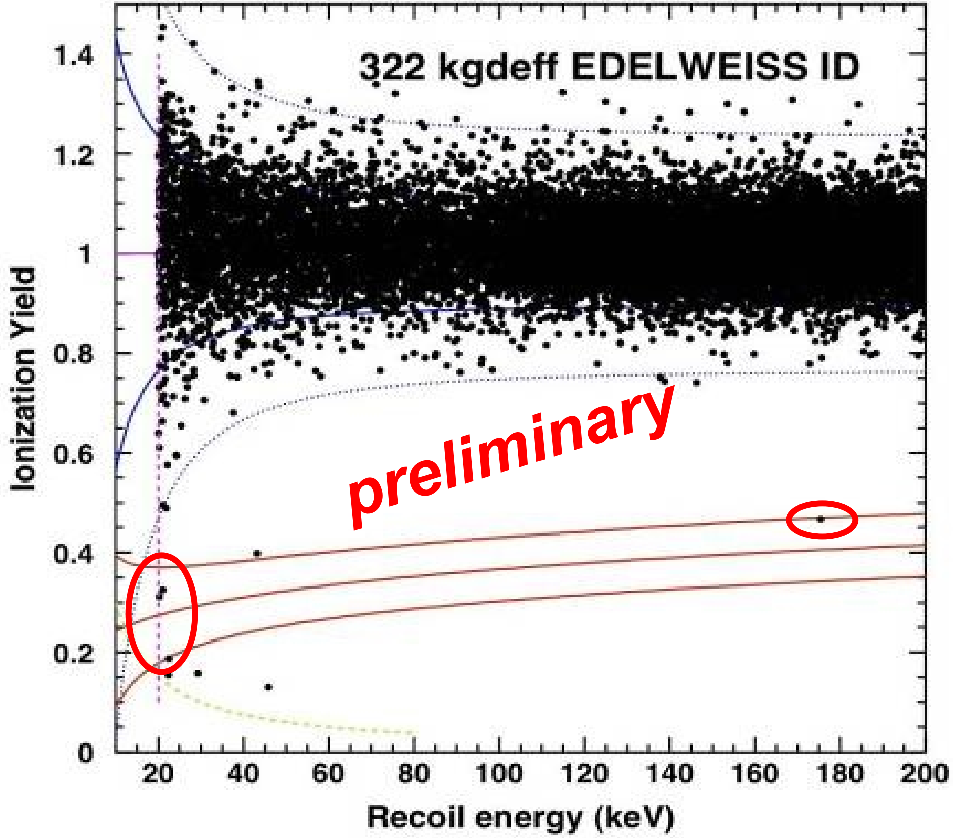
- **Beta rejection**
  ^{210}**Pb** source

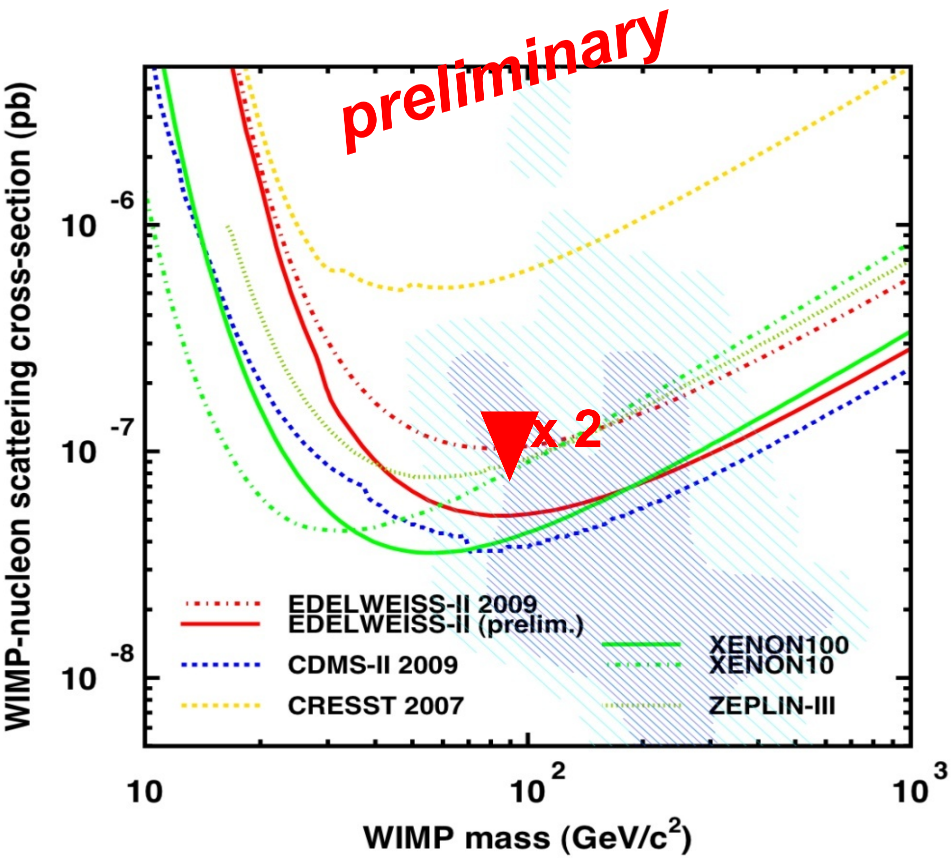


Phys Lett B 681 (2009) 305-309 (arXiv:0905.0753v1)

E. Armengaud, Colliquium APC, Feb 2010

EDELWEISS II WIMP Search
latest results (end of Run 20.05.10)





Preliminary result :

1st analysis with same cuts as first 6 months, 2nd analysis is ongoing

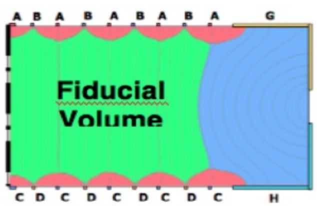
=> Increase in the sensitivity by factor of 2 (scales with statistics)

3 events near threshold in NR band (1 outlier) + 1 outlier (1 @ 175 keV in NR band)
bg estimate (preliminary!): < 1.6 events

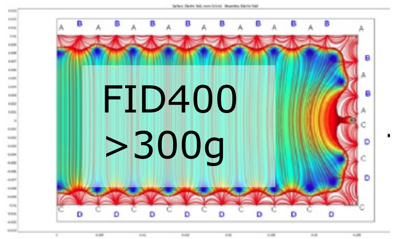
Best limit 5.10^{-8} pb at M(WIMP)=80 GeV

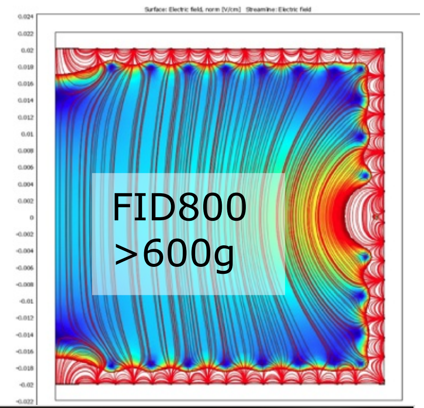
EDELWEISS II – Next Steps

- Doubling/Quadrupling the fiducial mass:
  ID400 => FID400 => FID800

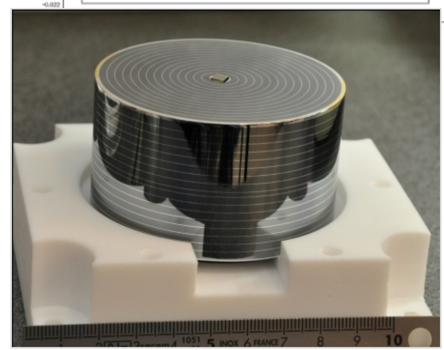


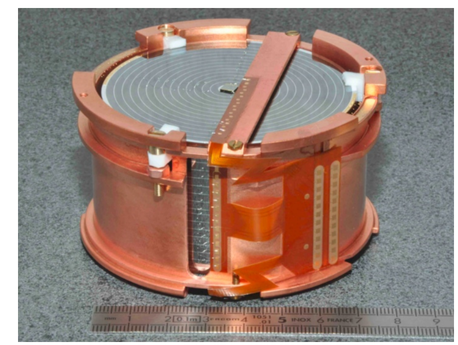
ID400 (160g)





FID800 (fully equipped)





- **Goals:** with FIDs 400+800g program, continue doubling of accumulated exposure every year

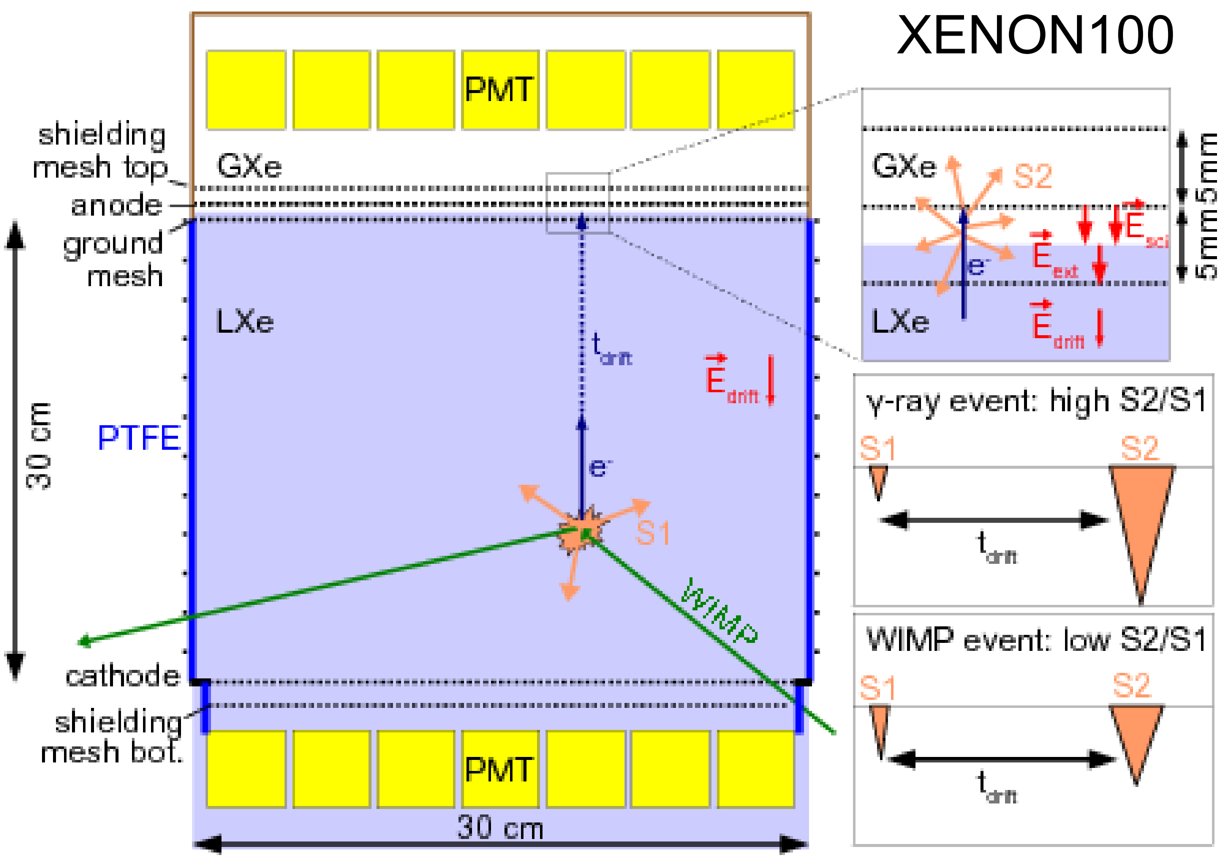
  2011 = 1000 kg.d 2013 = 3000 kg.d

- **2010 commissioning run with FID800 detectors:**

  4 FID800 installed July 3, 2010 ; T=20mK since July 27
  each 800 g detector with 2 NTD, 6 electrodes ◊ 2 «fiducial» volumes
  218 ultrasonic bondings / detector

The Liquid Xenon Dual Phase TPC
Ionization + Scintillation

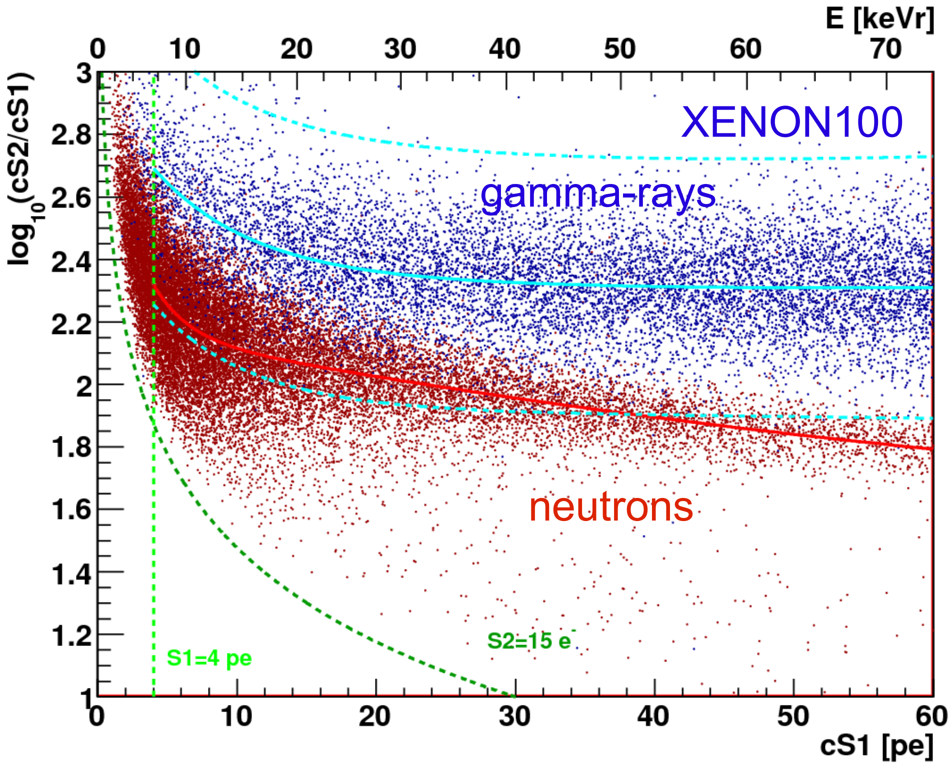
- Wimp recoil on Xe nucleus in dense liquid (2.9 g/cm^3)
  ⟶ Ionization + UV Scintillation
- Detection of primary scintillation light (S1) with PMTs.
- Charge drift towards liquid/gas interface.
- Charge extraction liquid/gas at high field between ground mesh (liquid) and anode (gas)
- Charge produces proportional scintillation signal (S2) in the gas phase (10 kV/cm)



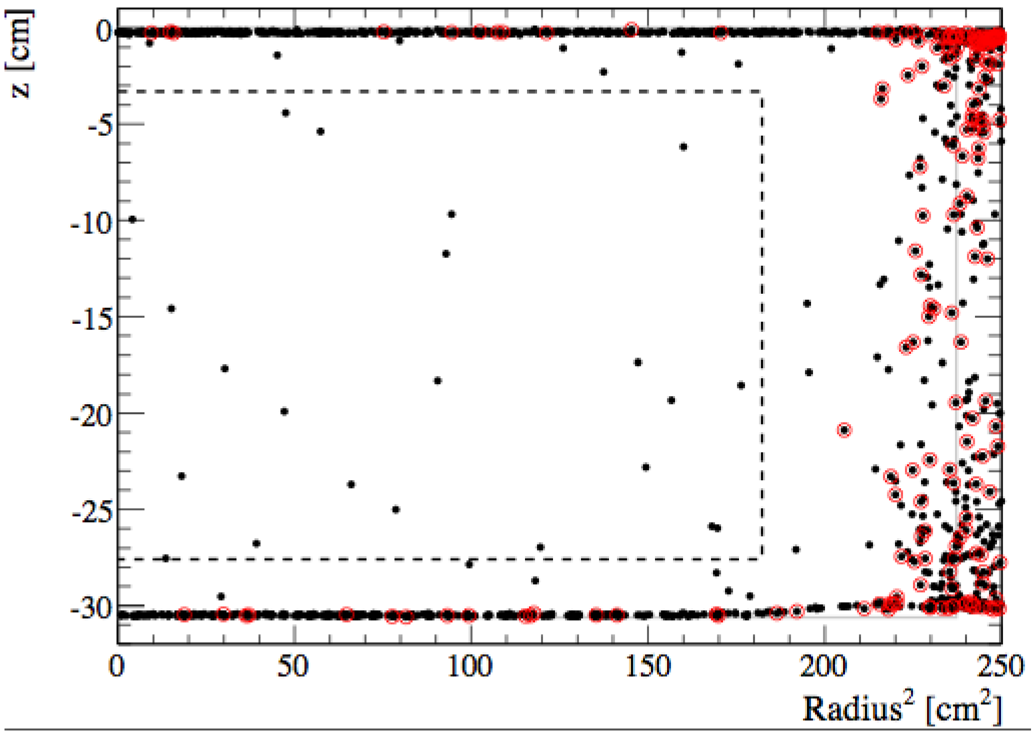
- 3D position measurement:
  - X/Y from S2 signal. Resolution few mm.
  - Z from electron drift time (~1 mm).

Background Discrimination in Dual Phase Liquid Xenon TPC's

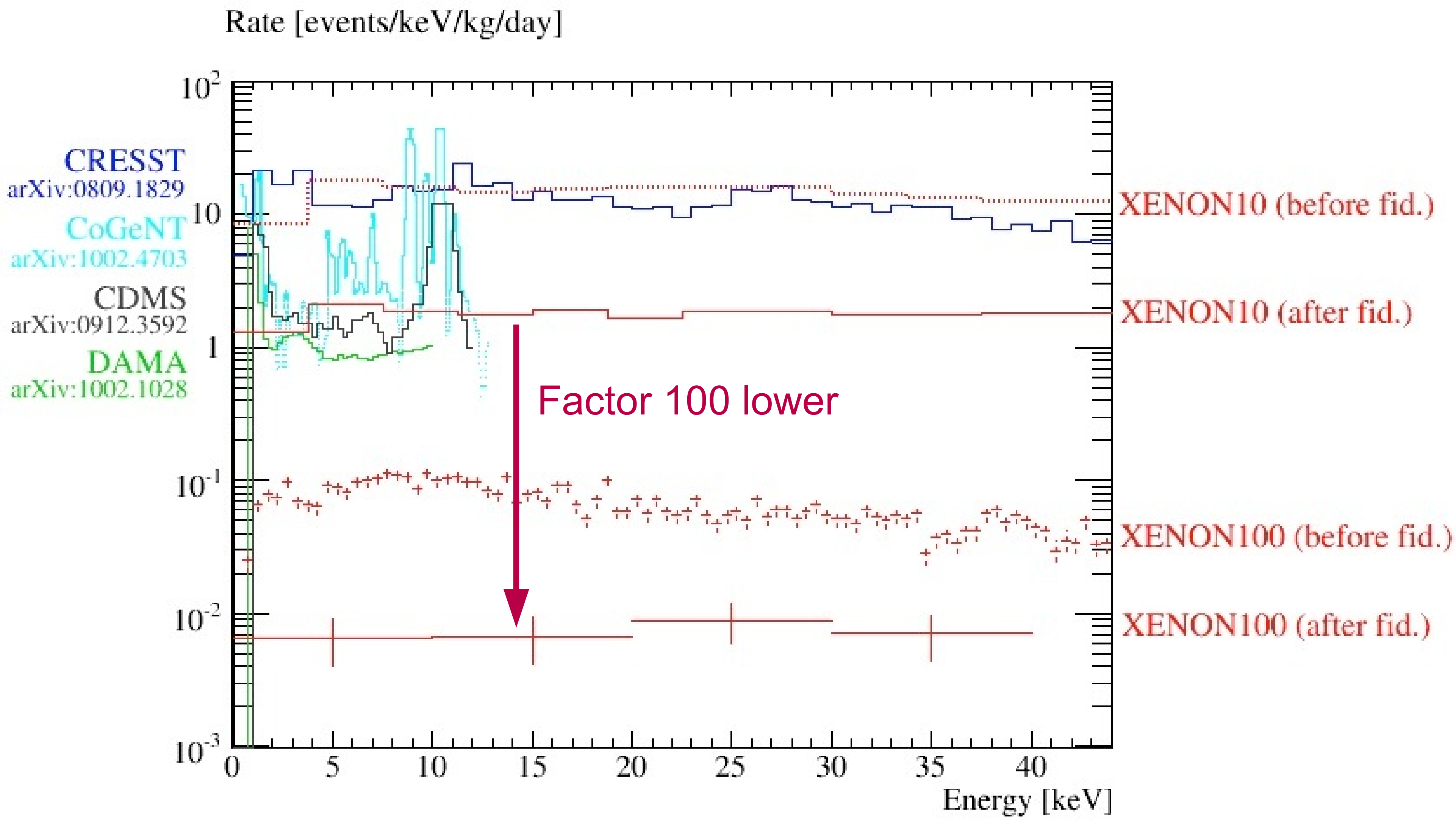
Ionization/Scintillation Ratio S2/S1



3D Position Resolution: fiducial cut, singles/multiples

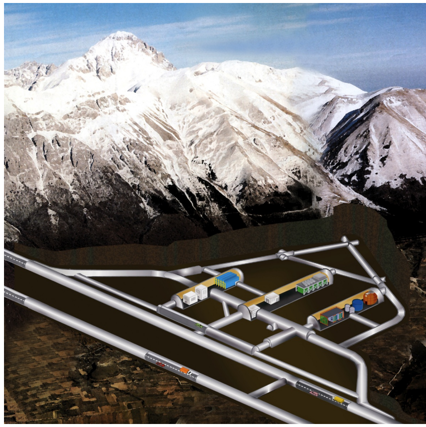


XENON100:
The Lowest Background Dark Matter Detector



The XENON Program

Collaboration: US (3)+ Switzerland (1) + Italy (2) + Portugal (1) + Germany (3) + France (1) + Netherlands (1) + Israel (1) + China (1)



GOAL: Explore WIMP Dark Matter with a sensitivity of σ_{SI}~10^{-47} cm^2.

- Requires ton-scale fiducial volume with extremely low background.

CONCEPT:

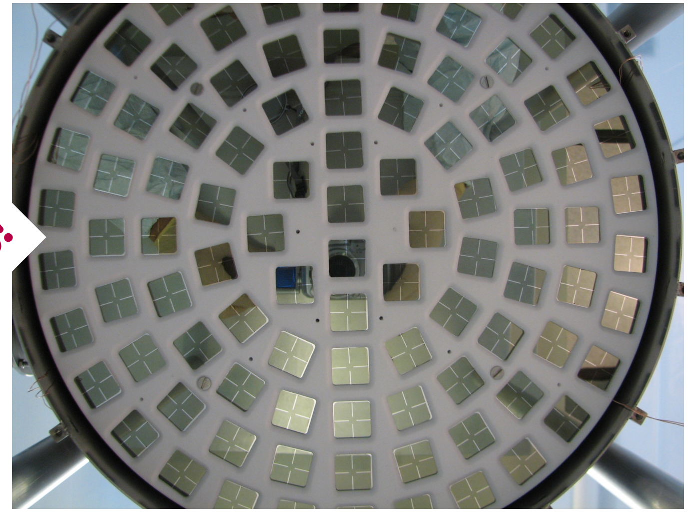
- Target LXe: excellent for DM WIMPs scattering.
  - Sensitive to both axial and scalar coupling.
- Detector: two-phase XeTPC: 3D position sensitive, self-shielding.
- Background discrimination: simultaneous charge & light detection (>99.5%).
- PMT readout with >3 pe/keV. Low energy threshold for nuclear recoils (~5 keV).

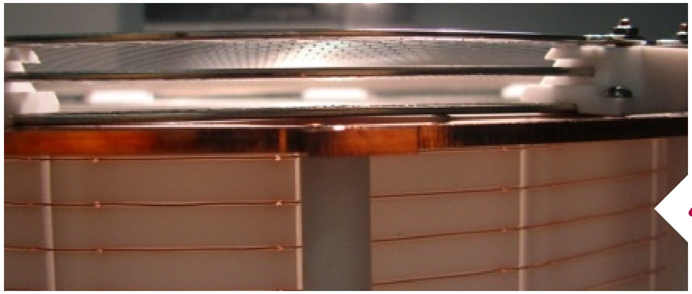
PHASES:

R&D	XENON10	XENON100	XENON1T
Start: 2002	2005-2007	2008-2011	2011-2015
	Proof of concept. Total mass: 14 kg 15 cm drift. Best limit in '07: σ_{SI}~10^{-43} cm^2	Dark Matter run ongoing. Total mass: 170 kg 30 cm drift. 11 days: σ_{SI}~ 3 x 10^{-44} cm^2 Goal: σ_{SI}~ 2 x 10^{-45} cm^2	Technical design studies. Total mass: ~2.4 t 90 cm drift. Goal: σ_{SI} ~ 3 x 10^{-47} cm^2

The Current Generation: XENON100 (2008-2011)

- 100 times lower background than XENON10
  - Material screening
  - Active LXe Veto
  - Upgrade of XENON10 shield (Cu, water)
  - Cryocooler/Feedthroughs outside shield
  - Low activity stainless steel
  - LXe self-shielding
- ~7 times larger target mass
  - 62 kg in target volume, 165 kg total LXe
- New PMTs with lower activity and high QE
- Improved electronics, grids, ...
- Gamma & neutron calibrations.
- DM search since Jan/13/2010.

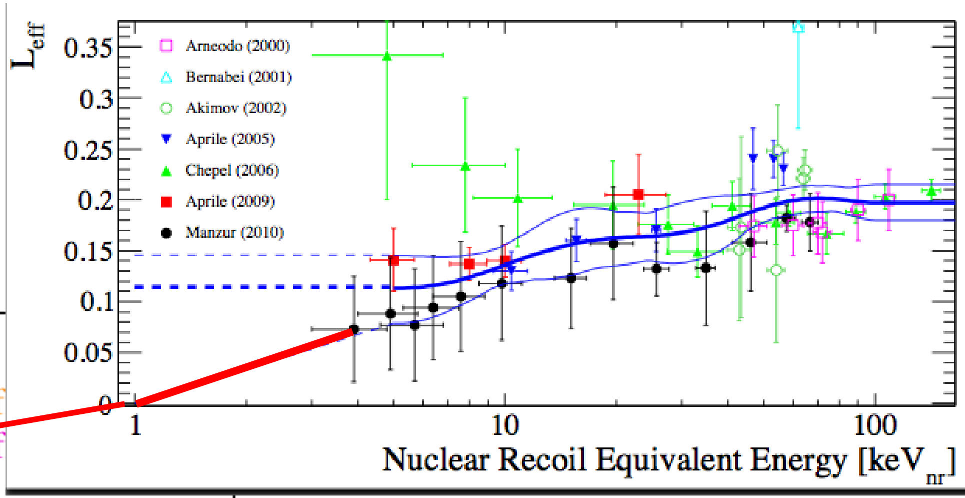


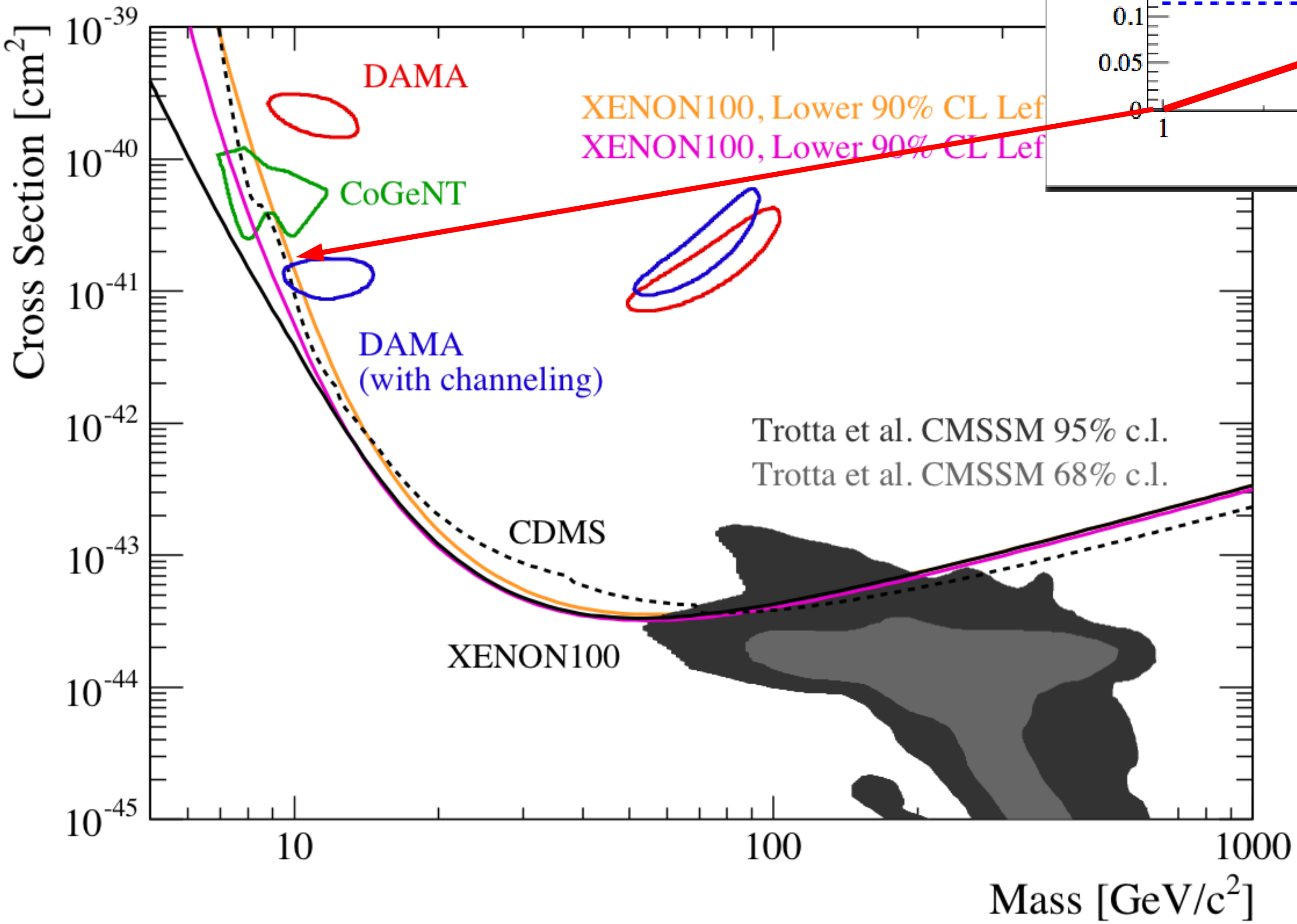


First results!

XENON100 Spin-Independent Limit

- 11.2 live days.
- 170 kg d spectrum-averaged exposure.
- Best SI upper limit of 3.4×10^{-44} cm^2 @ M_{DM} = 55 GeV/c^2





L_{eff}: lower 90%CL contour of global fit with logarithmic extrapolation.

Next Years - Germany

CRESST

MPI Munich, TU Munich, Tübingen
Oxford, Gran Sasso

- phonon-light
- W, Zn, Ca, O
- Gran Sasso

- 3kg fiducial running
- **goal: 15 kg nxt 2-3 yrs**
  with diff.targets in same setup

EDELWEISS

KIT Karlsruhe
Saclay, Orsay, Lyon, Grenoble, Dubna, Oxford

- phonon-charge
- Ge
- LSM

- 2kg fiducial running
- goal: 6 kg fid. in 2010
  20 kg fid. end 2011

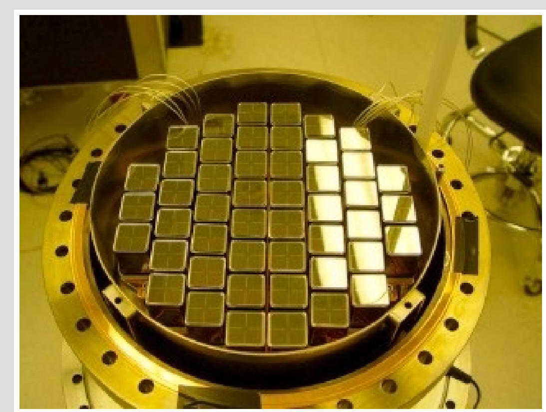
XENON

Münster, Mainz
MPI Heidelberg
Columbia, Rice, UCLA, Gran Sasso, Coimbra, Zürich, Subatech, Shanghai

- charge-light
- Xe
- Gran Sasso

- **50 kg fiducial starting**

next step will be 1t fid.



Future - Germany

CRESST

MPI Munich, TU
Tübingen
Oxford

• phonon-light
• W, Zn, Ca, O
• LSM

• 3kg fiducial runn
• goal: 15 kg nxt 2

EDELWEISS

Lyon,
a, Oxford

e

nning
10

EURECA

MPI Munich, TU Munich,
KIT Karlsruhe,
Uni Tübingen,
Oxford, Sheffield,
Saclay, Orsay, Grenoble,
Lyon, Dubna, Kiev,
Zaragoza

• phonon-charge/light
• Ge, W, Zn, Ca, O
• LSM

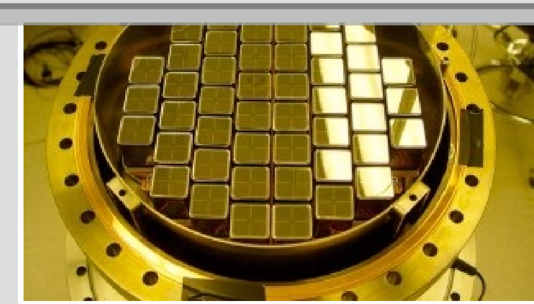
goal: 1 t   2015-2018

XENON

Münster, Mainz,
MPI Heidelberg
Columbia, Rice, UCLA,
Gran Sasso, Coimbra,
Zürich, Subatech, Shanghai

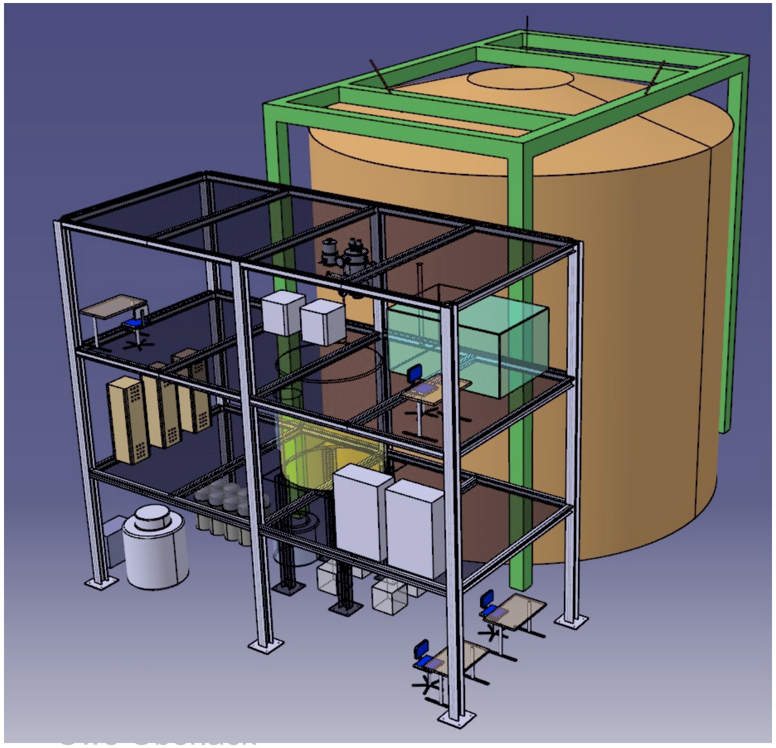
• charge-light
• Xe
• Gran Sasso

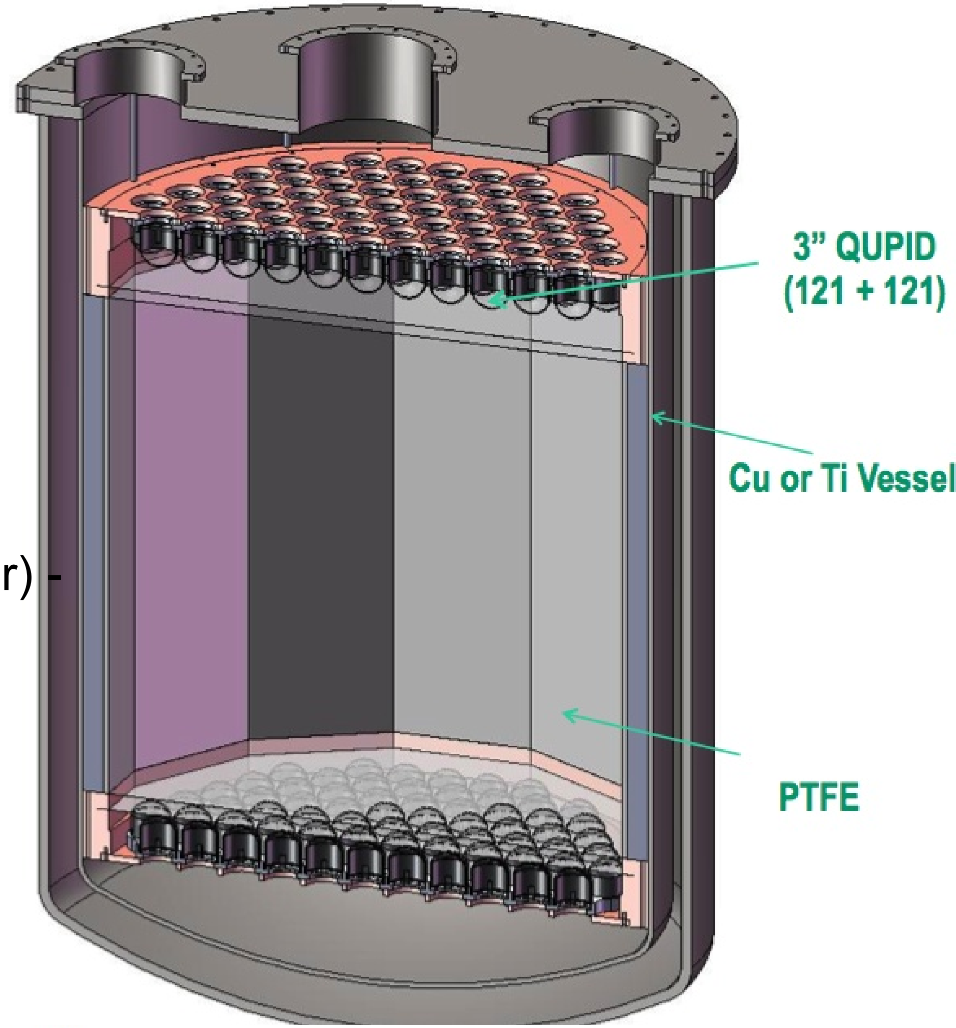
goal: start 1 t fid. 2013

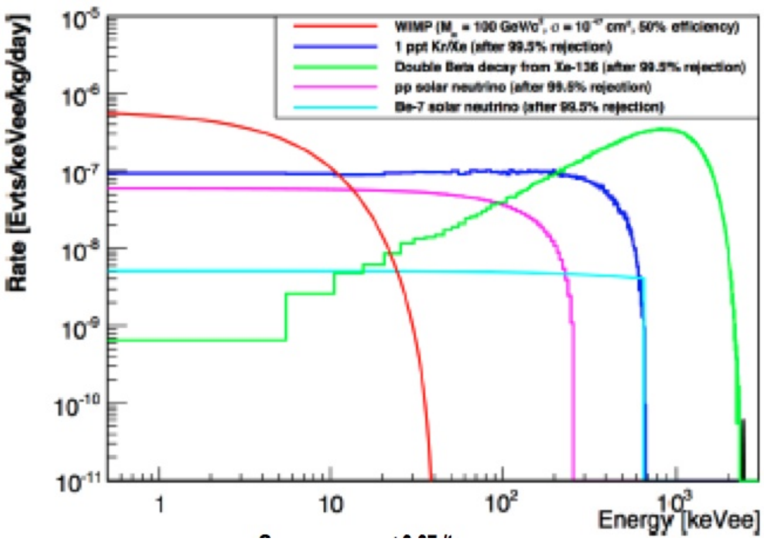


XENON-1T
(2011-2015)

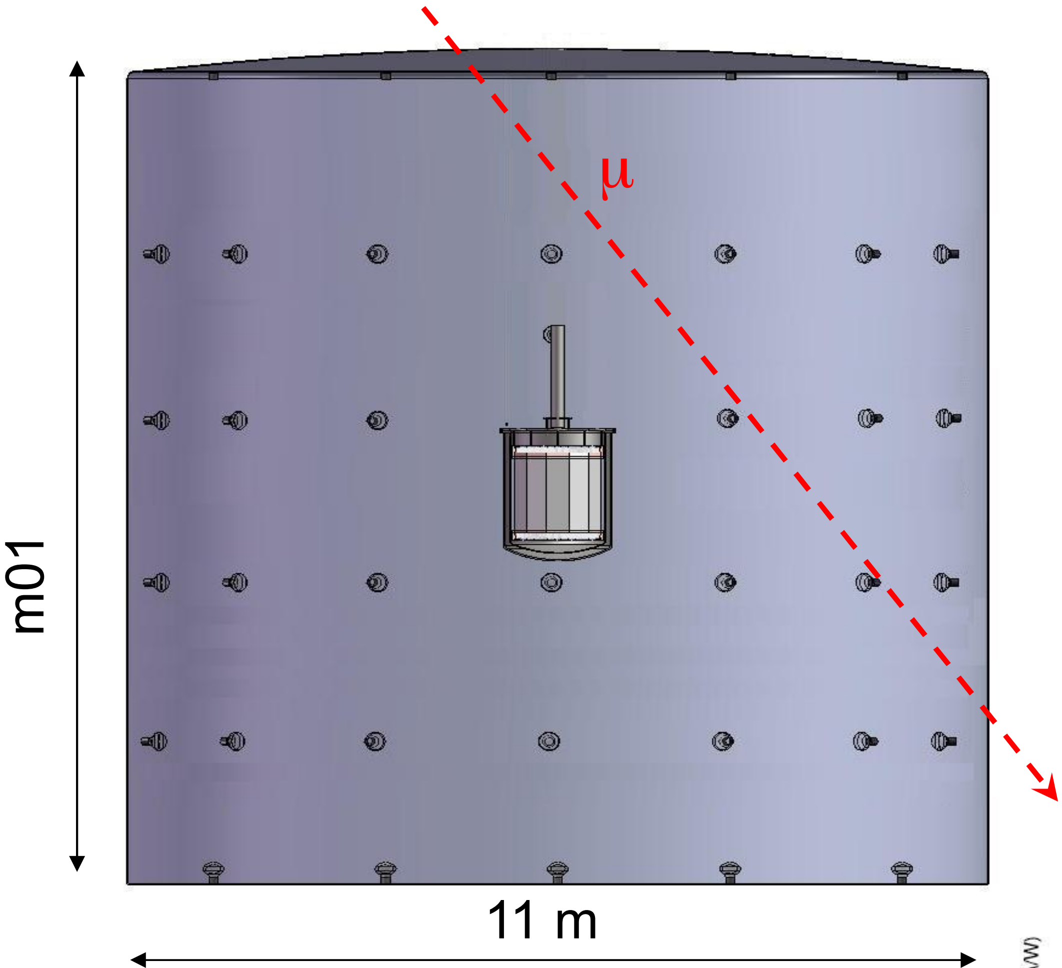
- 1t fiducial mass LXe detector to explore $\sigma \sim 3 \times 10^{-47}$ cm^2
- Water Cherenkov Muon Veto
- 2 x 121 3” QUPID's
- Capital cost: ~ $8.5 M, ~80% in hand
- Major German participation (MPI-K, Mainz, Münster) - BMBF proposal 2010
- Technical proposal submitted to LNGS Oct. 2010
- Alternate location: LSM







XENON1T Water Cherenkov Muon Veto

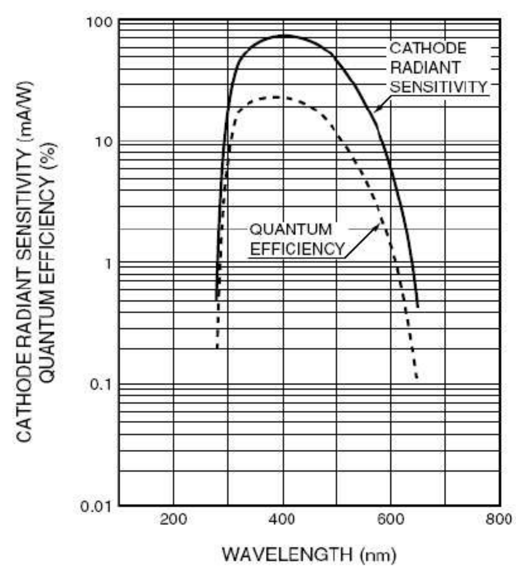


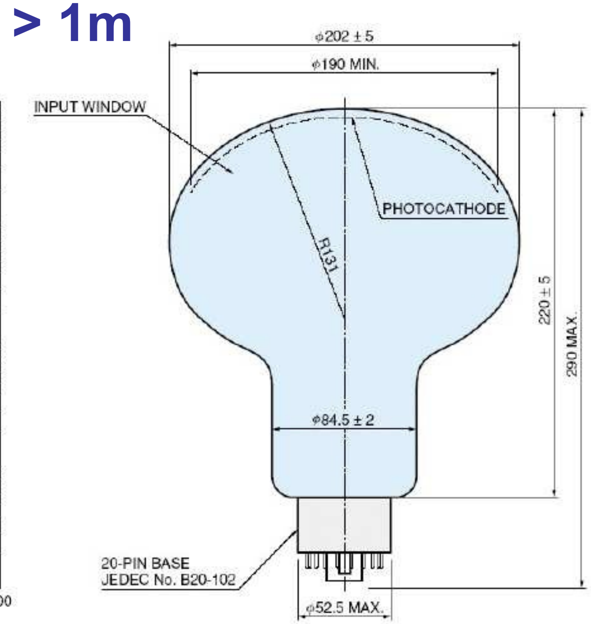
- 4 rings of 12 PMTs in the lateral surface
- ~ 30 PMTs in the bottom floor in an hexagonal grid.

From the MC:

- On average 23 ph.el. / PMT
- **Muon detection efficiency ~100% for track > 1m**

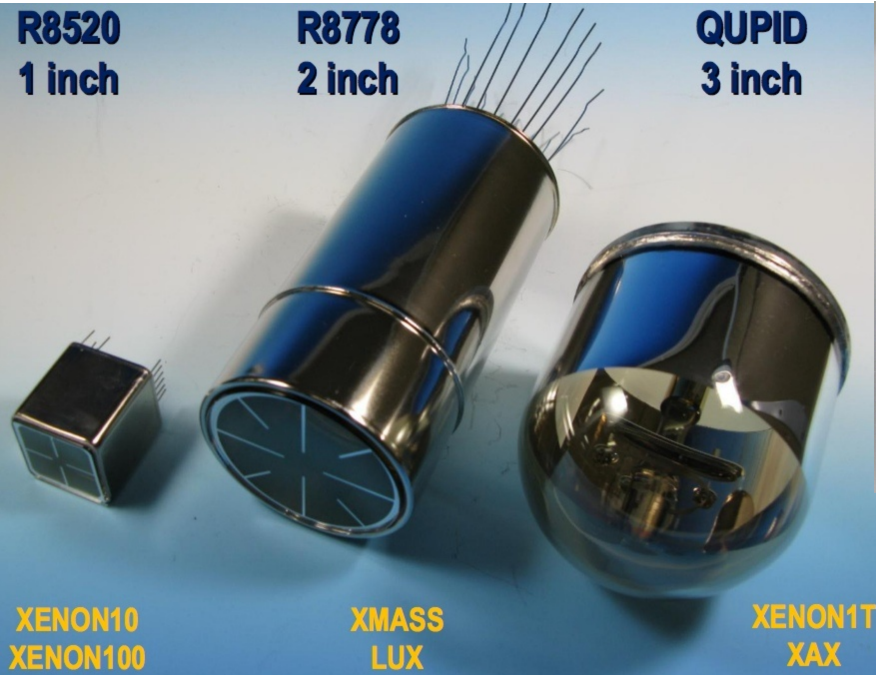
PMTs:
8” Hamamatsu R5912
in the water-proof version.



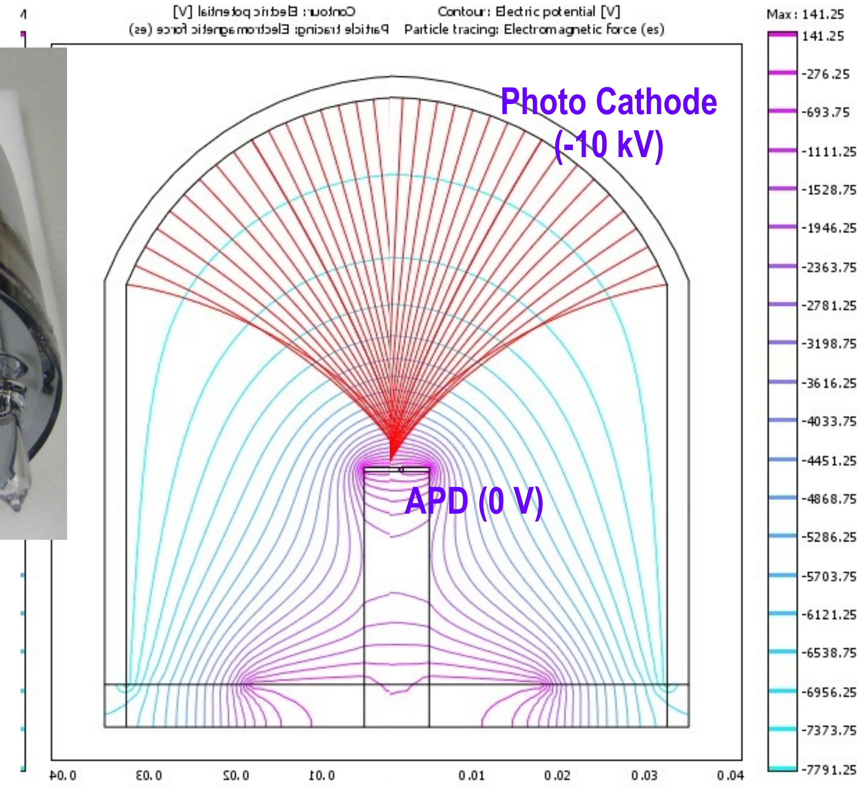


Reflector foil:
ER2000MA by 3M, reflectivity 98%.

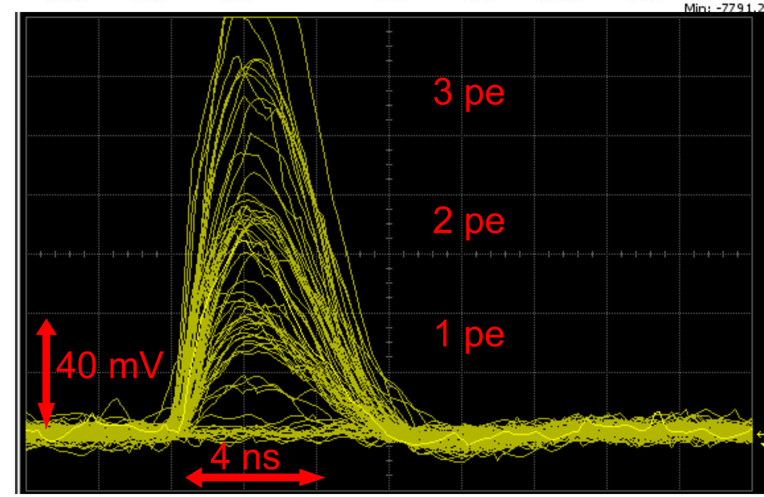
New Photosensor for XENON1T: 3” QUPID



K. Arisaka & H. Wang (UCLA)



- > Ten-fold reduction in radioactivity per unit area. (< 0.02 mBq/cm^2)
- Single photo-electron resolution.
- Single HV supply for many channels.
- Large dynamic range.

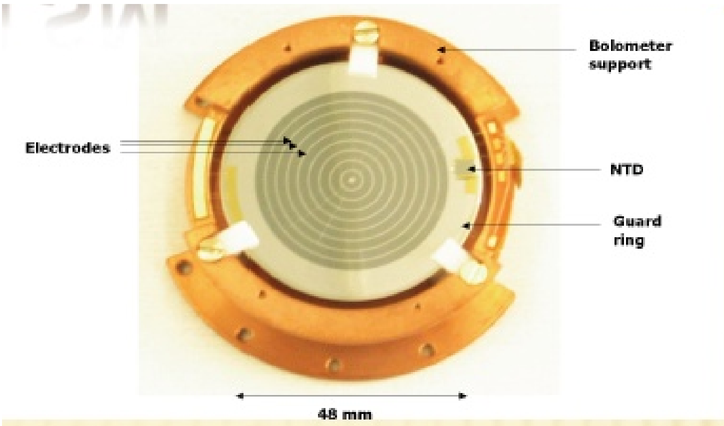


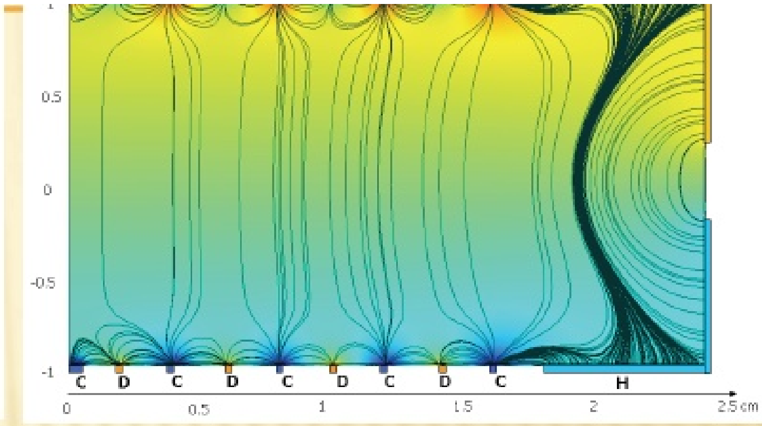
EURECA: Combining Cryogenic Detection Techniques

European Underground Rare Event Calorimeter Array

Phonon - Charge (EDELWEISS)

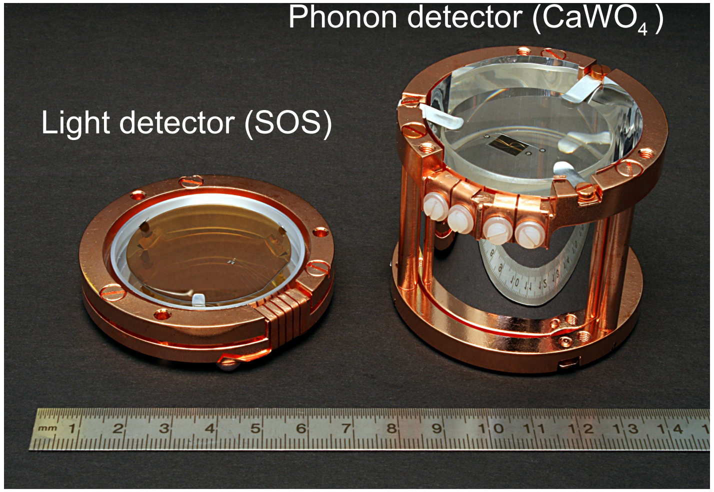
Ge detectors with surface event rejection (interdigit)

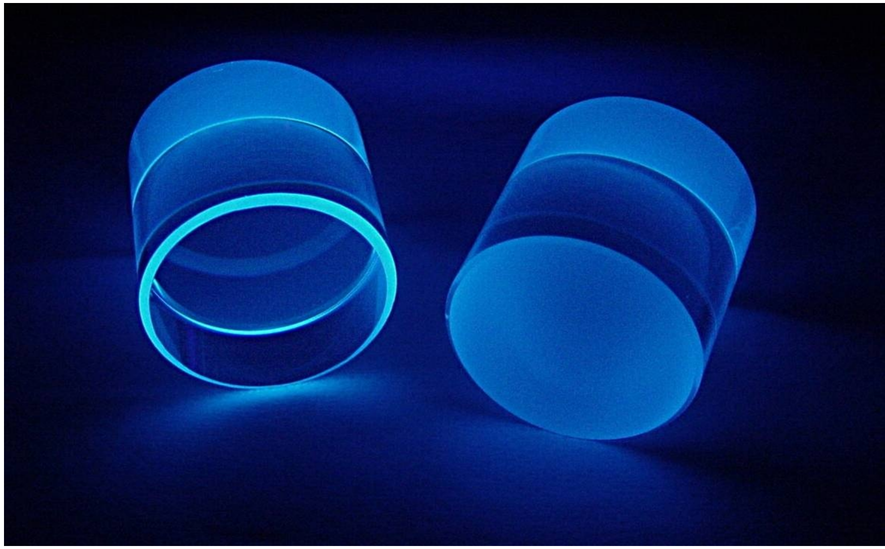




Phonon - Scintillation (CRESST, ROSEBUD)

Event by event discrimination in scintillating $CaWO_4$ detectors





Phonon-scintillation technique allows flexibility in choice of target materials: $ZnWO_4$, $CaMoO_4$, BGO, Al_2O_3, NaI ...

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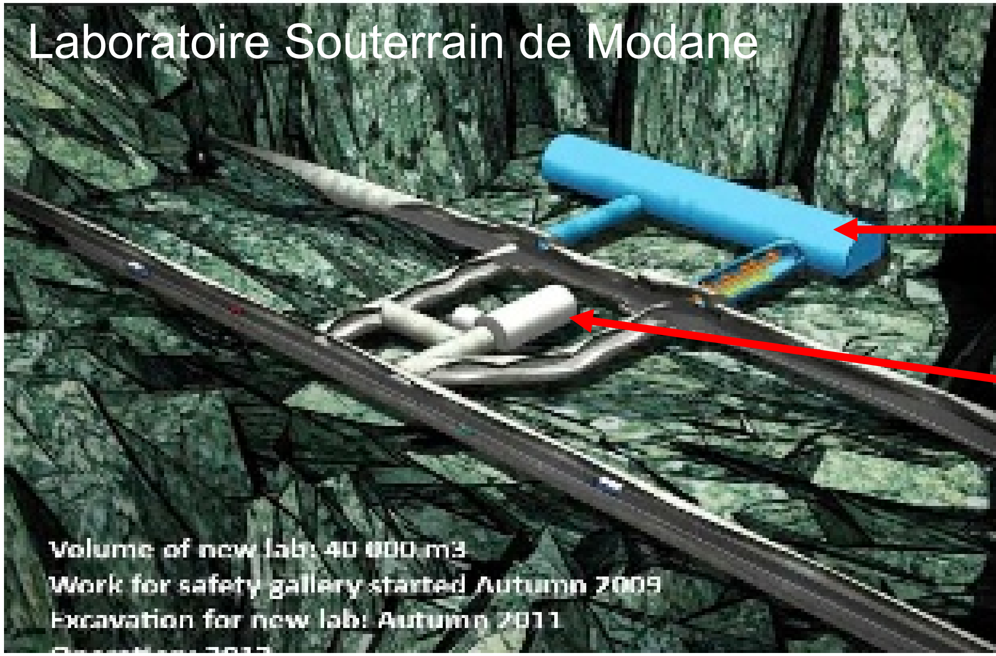
Present Design of EURECA at LSM Extension



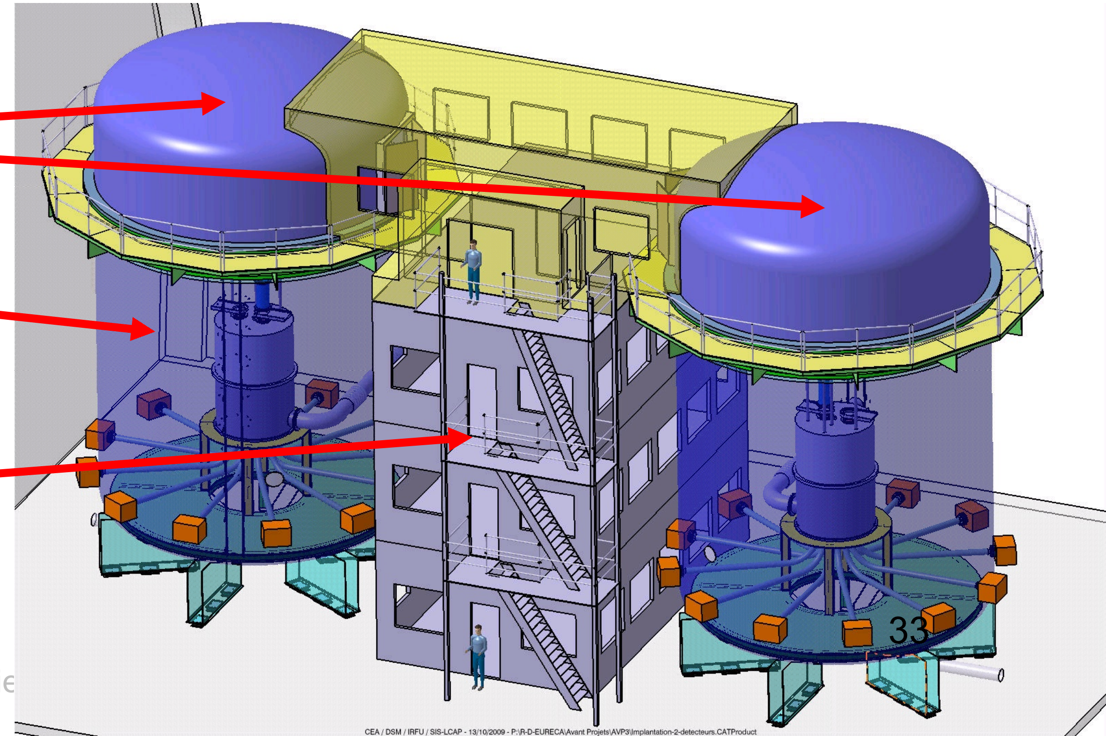
Planned extension ULISSE:
decision expected by end of 2010

Existing LSM laboratory

2 individual cryostats

Shielding: ~3m of water
Instrumented with PMTs to act
as active water Cherenkov muon-veto

Cleanrooms and infrastructure



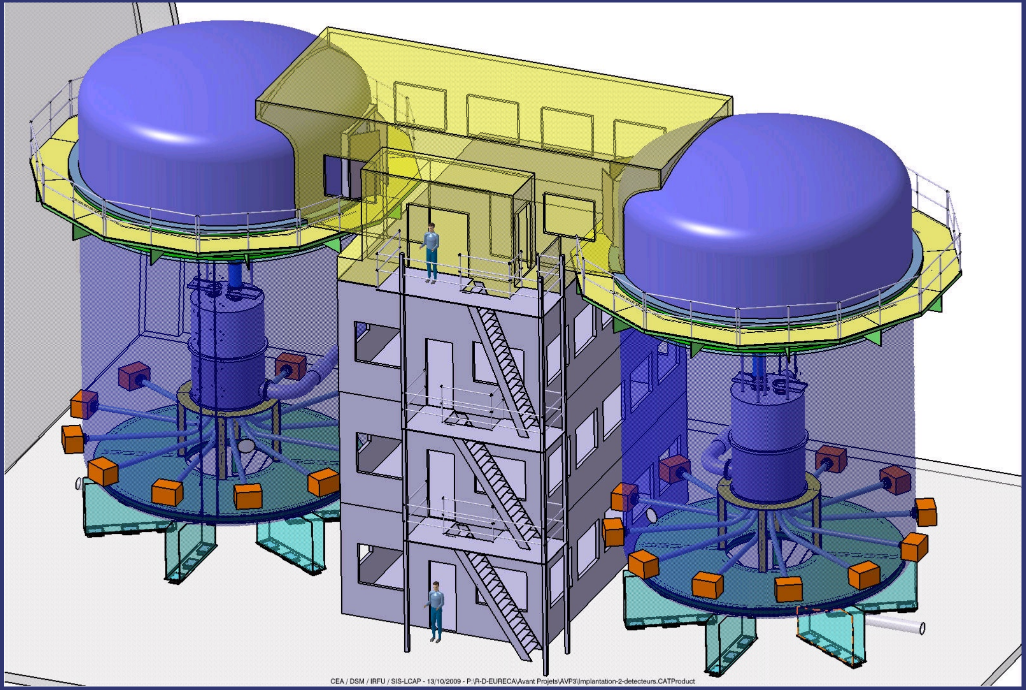
EURECA

Germany, France, UK,
Spain, Russia, Ukraine

R&D cooperation with US groups
common workshop EURECA / CDMS 2011

2009/10: design study => TDR
funded in France, Spain Aspera Common Call)

2012/13: LSM excavation
saftey tunnel drilling has started
+ construction EURECA components
~ 100 kg fiducal target at present sites,
~ 10^{-45} cm^2



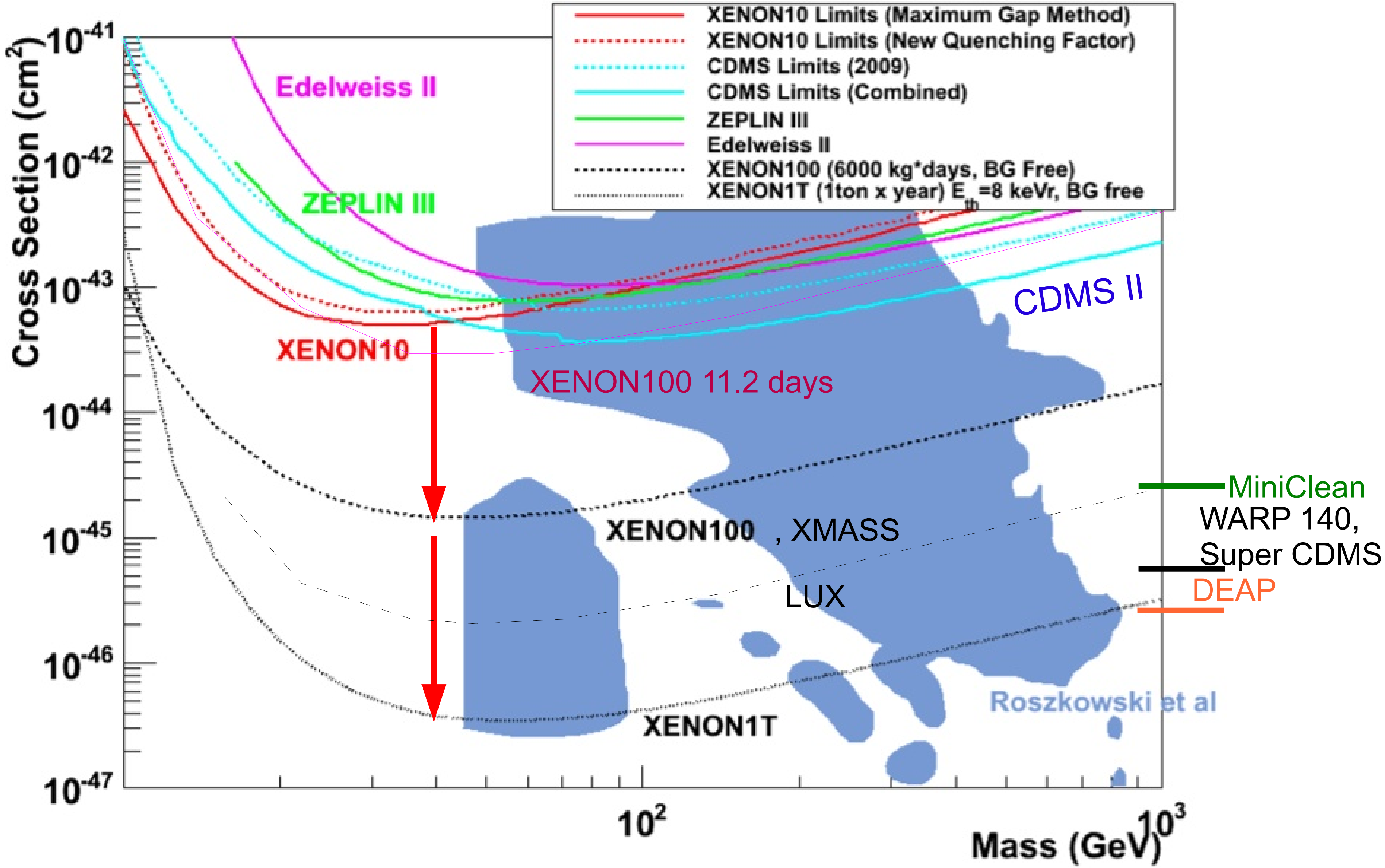
2013/14: construction at LSM

2015: begin data taking at LSM

2015 – 2018:
- continuous upgrade to 1t target
- ~ $10^{-46} cm^2$

The Future of WIMP Searches

Spin-Independent Sensitivity (indicative)



Summary & Outlook

- Dark Matter direct searches have advanced in sensitivity by >2 orders of magnitude in the last decade. Fast-paced progress, getting faster.
- Noble liquid detectors have matured and will likely set the pace in the next 5+ years.
- New approaches in cryogenic detectors aim at improving scalability. Ge: Big step in background reduction with interleaved charge readout, plus larger detectors.
- Several **exciting new results in the last year**:
  - CoGeNT, CRESST excess events (& DAMA/LIBRA annual modulation): Low mass WIMPs?? Or poorly understood backgrounds?
  - XENON100 background-free in 40 kg with 11 days exposure, limiting any low mass WIMP interpretation to < 10 GeV/c^2. (Improvements upcoming.)
  - Big improvement in sensitivity just months away.
- Observed “hints” demonstrate a fundamental need in this field: verification with **different targets** and **different technologies** with different systematics.
  The first time we see Dark Matter, it will look much like these results ... a few unexplained events.
- In pushing senstivities by orders of magnitude, any one technology may hit a roadblock. Diversity is important. But different technologies are likely to proceed at different rates.
- Germany is well positioned with expertise in cryogenic detectors and, more recently, the liquid xenon TPC. Need for moderate investments in the next big steps.
- The discovery of Dark Matter may be around the corner!
  But hikers know that a nearby looking summit can still be far away – persistance is required.
- With LHC, direct, and indirect searches, we will learn much about DM in the next 5 years. Will we have solved the puzzle by 2020?

Thanks for input by J. Jochum, K. Eitel, J.C. Lanfranchi, E. Aprile, and others.

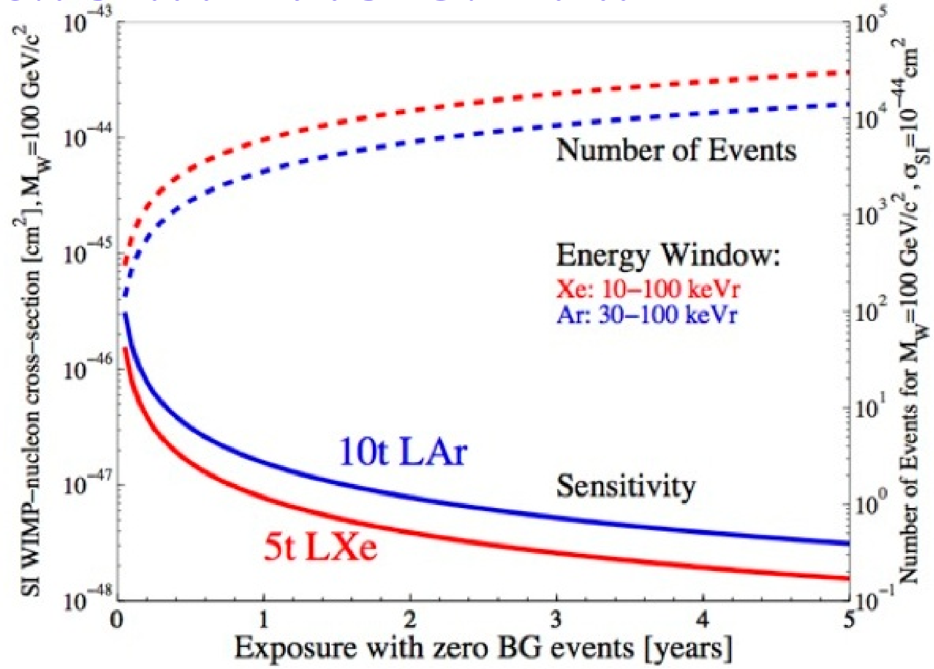
BACKUP SLIDES

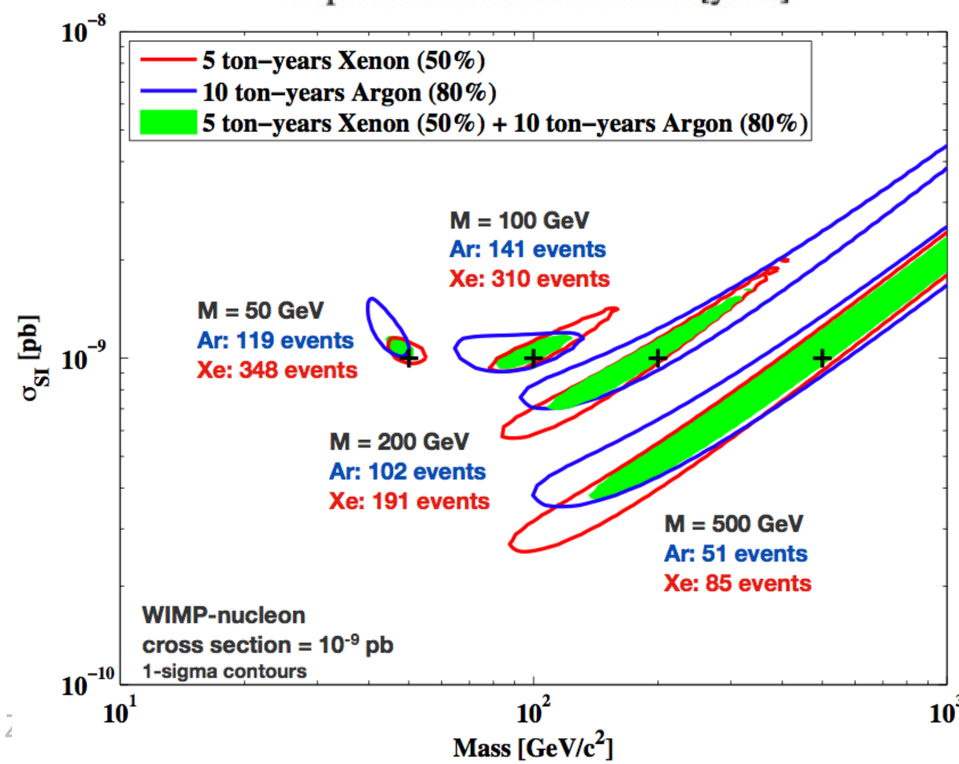
Studying the Multi-ton Scale in LXe & LAr

DARWIN

- R&D and design study over 3 years for a next-generation noble liquid facility in Europe
- Approved by ASPERA (AStroParticle ERAnet) in late 2009
- Funded in Switzerland, Italy, France, Netherlands
- Combine efforts in both LAr and LXe
- Europe: UZH, INFN, ETHZ, Subatech, Nikhef, MPIK, Münster, Mainz, KIT, IFJPAN
- USA: Columbia, Princeton, (Rice), UCLA

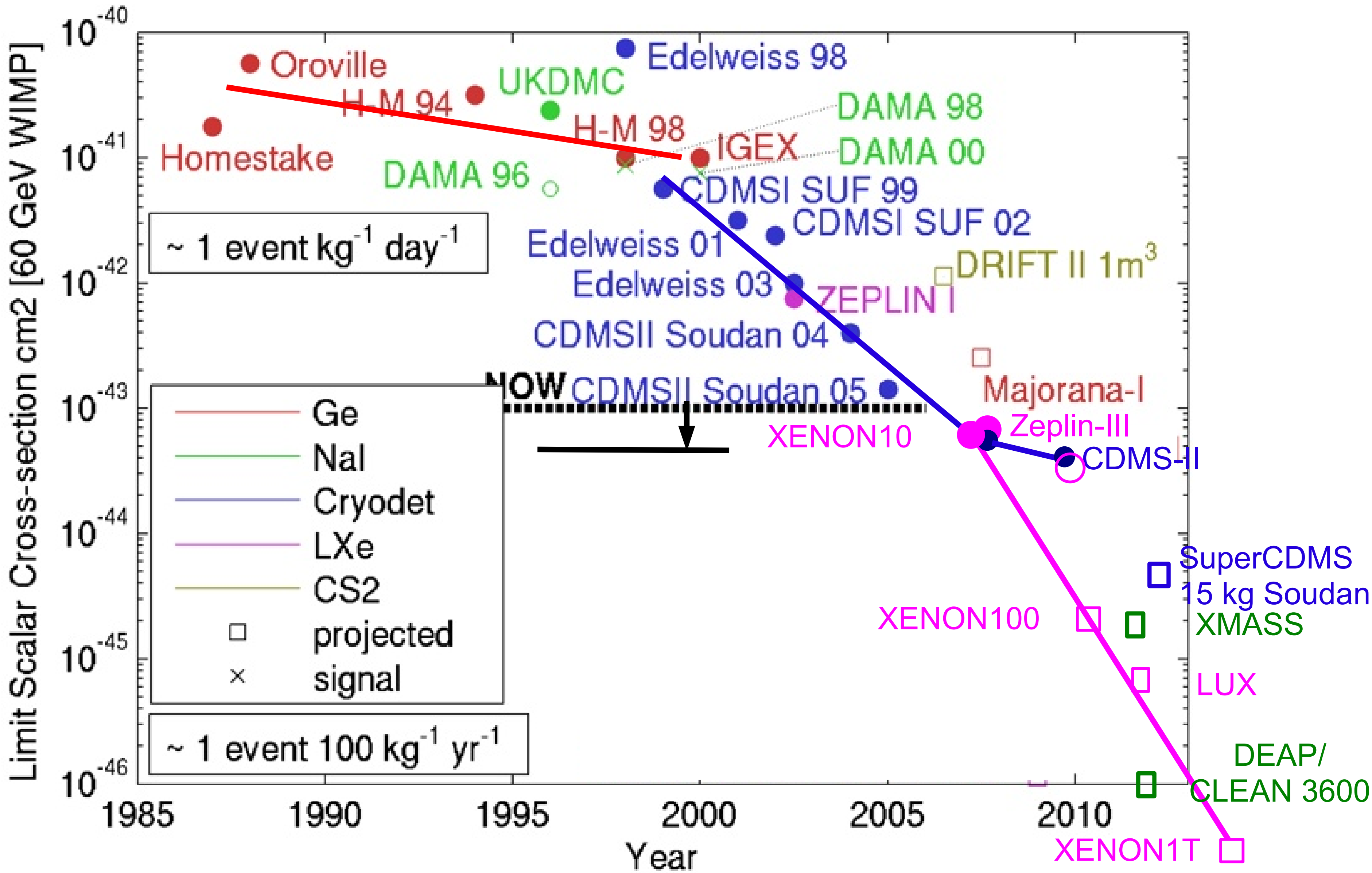
Details: darwin.physik.uzh.ch





DM Direct Searches - Progress Over Time

Spin-Independent Interactions



Plot updated from DM Review: R. Gaitskell, Ann. Rev. Nucl. and Part. Sci. 54 (2004) 315-359

Backgrounds in Direct DM Search

Cross-sections are *very* small: <10^{-43} cm^2 or 10^{-7} pb (spin-independent)

Without background, sensitivity $\propto$ (mass × exposure time)$^{-1}$

With background subtraction $\propto$ (M t)$^{-1/2}$
until limited by systematics.

Backgrounds:

Gamma-rays & beta decays:

~100 events/kg/day
Need very good β and γ background discrimination.
Shielding: low-activity lead, water, noble liquids (active), liquid N_2, ...

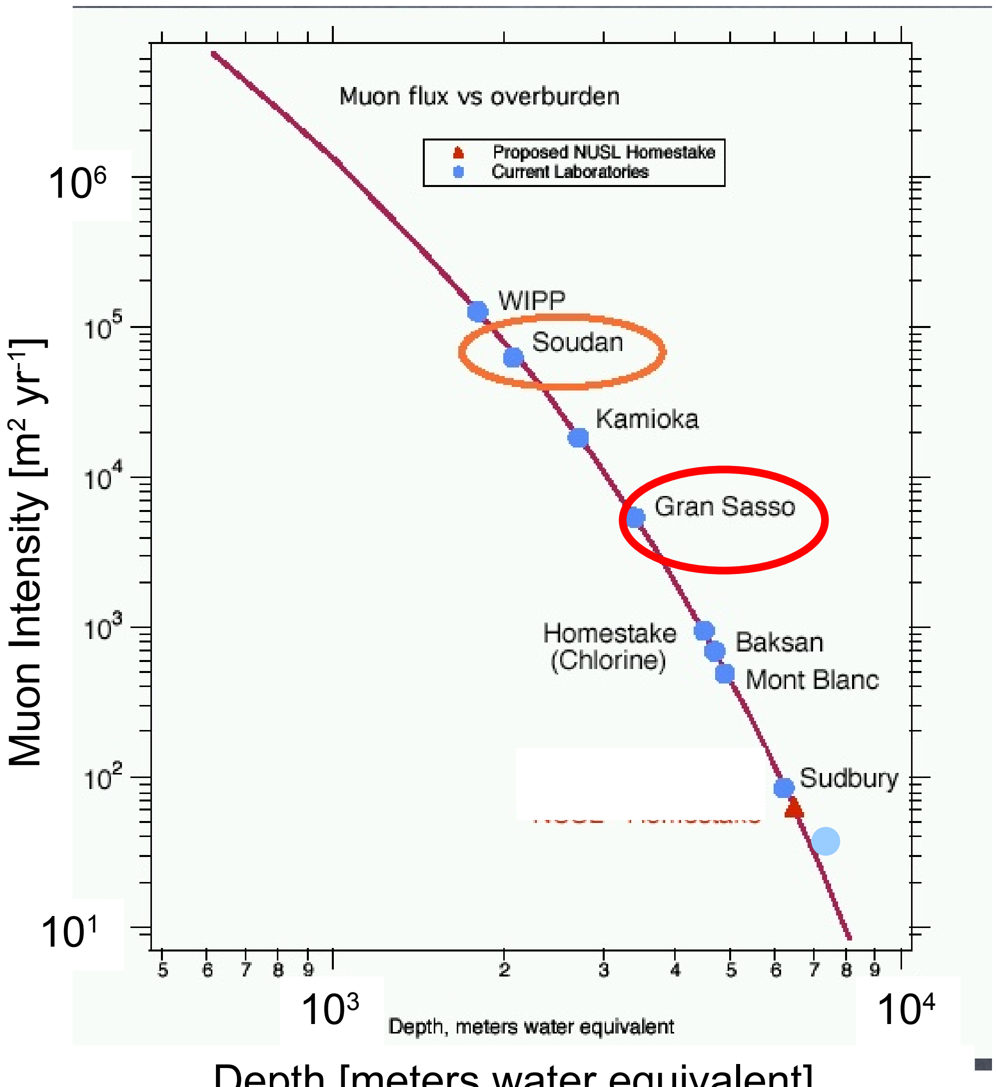
Neutrons from (α, n) and spontaneous fission (concrete, rock, etc.):

~ 1 event/kg/day (LNGS)
Neutron moderator (polyethylene, paraffin, ...)

Neutrons from CR muons:

Rate depending on depth.
μ-veto, n-veto, shielding

α decays from Rn daughters, ...



XENON1T Cryostat in Water Tank